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A Fire History Study - toward a community protection plan for Fort Smith, NT

by

Hanita Maria Brungs Simard ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements for the degree of Master of Science.

Department of Biological Sciences

Edmonton, Alberta

Fall 2001

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The undersigned certify that they have read, and recommended to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **A Fire History Study - toward a community protection plan for Fort Smith, NT** submitted by **Hanita Maria Brungs Simard** in partial fulfilment of the requirements for the degree of **Master of Science.**

Abstract

In the boreal forest of northern Canada forest fires have increased in number and size over the past decades. To support a community protection fire management plan, a fire history study was carried out in a 595 km^2 area to the south and west of Fort Smith, NT (60°00' N and 111°55' W). Estimations of time since last fire indicate four fire regimes with fire cycles of 181, 267, 29, and 130 years since 1865. Correlation of tree-ring variables with Fire Weather Index components were extremely weak, but DMC was significantly correlated to ring width and earlywood width tree series for jack pine, and was also significantly correlated to trees found in sites that experienced fluctuating moisture levels. To identify fuel corridors and breaks, vegetation was classified according to the Alberta Wetland Inventory and mapped.

Acknowledgements

Thanks to my supervisory committee for their support: each member had their own niche. To Ross Wein, who bore the brunt of the supervision, and for providing the initial inspiration and ongoing support for the project; Mark Dale, for generously solving the problem of being shared between two faculties and for the Thursday evening presentations and statistical help; Ian Campbell, for permitting me to regularly darken his doorway at the Northern Forestry Centre and dealing with the tree rings and numerous computer problems. Finally, to Don Pluth who agreed to become a committee member rather late in the process.

This project would not have happened without Rick Lanoville of Resources, Wildlife and Economic Development in Fort Smith, who gave the initial proposal tighter focus, and was responsible for the majority of the funding and bringing Wood Buffalo National Park into the project (WBNP provided the helicopter time). Additional funding was also provided by the Canadian Circumpolar Institute (CCI), the Territorial Forest Fire Centre (now known as Resources, Wildlife and Economic Development), the Town of Fort Smith as well as SEED and the South Slave Research Centre.

Heartfelt thanks go out to the community members and various agencies in Fort Smith who made my summers there a wonderful experience. The guidance and support provided by Ruthann Gal was invaluable; I am grateful to have had such an understanding coordinator and friend! Frank Lepine and Paul Johnson of the regional Renewable Resources Office contributed greatly to the direction of this project, as have Mike Etches with Steve Otway of Wood Buffalo National Park. Dennis Bevington, past mayor, was always interested and encouraging, and was instrumental in ensuring the project went ahead.

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Avery, our new daughter of 15 weeks: your arrival inspired me to complete this project!

Finally, to my darling husband Chris, who always has faith in me.

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General Introduction

The general world-wide movement of people from rural to urban areas has recently been countered to a great extent by urbanites moving to rural areas (Close & Wakimoto 1994, Davis 1986). This population shift reflects the increased interest in visiting and living in the wildlands (Bethea 1988, Davis 1986, Keeley *et al.* 1999). As more and more people seek out peace and tranquillity, they establish themselves more firmly and frequently in wildland areas, and the result is uncontrolled growth in the interface between urban and wildland areas (Close & Wakimoto 1994). Nature is perceived as being soothing, healing, and benevolent, and therefore many people are initially unaware and unprepared for the potential dangers at the wildland/urban interface (WUI) (Davis & Mutch 1983). However, they soon learn that nature is an impressive force and that there can be unpleasant encounters with both fauna and flora, as well as with natural disturbances such as floods, avalanches, and fire. As these types of experiences become more frequent, and public awareness programs become more sophisticated and widespread, the public is gradually acquiring knowledge and is becoming better prepared to deal with the WUI.

At the WUI, few issues are more significant than fire in conifer dominated ecosystems. This is because fires play an important role in maintaining the health of many ecosystems but also threaten lives, property, resources, economic welfare, and even viewsheds. Therefore, fire management policies and procedures are being developed specifically for the WUI throughout many parts of the world (Hirsch 1992, Kalabokidis & Omi 1998, Tymstra 1994).

The importance and inevitability of fire in many ecosystems is becoming widely known and accepted, not only among scientists, but also among the general public. Over the past thirty years there has been a growing understanding that efforts to eliminate fire from the ecosystem have caused even greater problems than if fire had been permitted to remain as part of a healthy forest environment. There is also the recognition that fire can be used as a management tool (Angelstan 1998, Arno 1980, McBride & Laven 1976, Payette *et al.* 1989, Weber & Stocks 1998, Wein & Moore 1977). Acceptance of fire as a natural and essential part of a number of ecosystems has been slower in the non-scientific community,

although certain fire events, including Yellowstone Park, and their portrayal in the media, such as National Geographic magazine (September 1996), have contributed to the growing public awareness of the environment and the important role that fire plays in many ecosystems.

Although WUI issues in Canada may not be as critical as they are in other countries (due to our large land base and relatively small population) Canada's issues are unique because of the large area that is covered by the boreal forest, the average area burned, and the scattered communities that are found within this forest type. About 30% of Canada's land area is covered by the boreal forest which is the largest forest region in Canada at 315 million ha. (Weber & Stocks 1998). This forest region consistently experiences the highest average of annual area burned, the last two decades having the greatest annual area burned on record (e.g. 7.3 million ha. in 1995). It is also important to note that fire occurrences have also been increasing: from 1930 to 1960, approximately 6 000 annual fire occurrences were recorded, while during the 1980s there were approximately 10 000 annual fire occurrences. This increase could be due to a number of factors, including increased population, the movement of people into the WUI (both of which result in greater forest use), as well as better fire detection systems. In Canada, lightning causes only 35% of all fires, but these same fires are responsible for 85% of the total area burned. The largest burned areas are found primarily in more remote regions, as the greatest percentage of lightning-caused fires occur in remote regions of the boreal forest (Weber & Stocks 1998).

The human population above the 60th parallel is very small, being only 99 278 for the three territories, with 41 606 of these living in the Northwest Territories (Statistics Canada 1996). Although most of this population lives in the larger centres, many live in smaller, somewhat more isolated, communities. Residents of Canada's north are well aware of the threat of fire, with hundreds of fires burning every summer, many of which are permitted to burn because of few values-at-risk. However, almost every fire season one or more communities are threatened: fires near Old Crow in 1989, Norman Wells in 1993, Trout Lake in 1994, Norman Wells again 1995 and Fort Smith in 1998 are prominent examples (Resources,

Wildlife and Economic Development staff, *pers. comm.* 1996). The problem may intensify: it is predicted that fire frequency and severity may change due to global warming, with the most extreme effects occurring in the northern regions (Flannigan & Van Wagner 1991).

Protecting an urban area from wildfire and developing a successful fire management plan involves identifying and understanding the type or types of interfaces present (e.g., classic, mixed and occluded), as well as the past, present and future role of fire in the region, and planning the management of fire not only in the short-term, but also for the long-term in the face of changing community needs and global warming (Hirsch 1992, Kalabokidis & Omi 1998, Laughlin & Page 1987, Tymstra 1994). Some of the scientific considerations which should be included in management plans centre around understanding the historical role of fire, that is, estimating fire cycle and fire frequency, and reconstructing both fire and drought (potential fire) chronologies which can be linked to vegetation types and perhaps even to anthropogenic events. Land use must also be considered, as the immediate needs of the community must be balanced with the health of the forest.

Objectives

This study had three objectives. The first was to determine, through an analysis of fire scars, the fire history of the Fort Smith area. The second was to establish the relationship between tree growth (annual ring width and density) and critical fire weather. The third was to classify the vegetation in the study area for identification of fuel corridors and breaks. The research that relates to these three objectives is presented as three chapters.

Chapter One

It was the development of fire management plans within the U.S. park system in the early 1970s that lead to the resurgence in fire history studies, with the dating of fire scars being the most common method used (Arno & Sneck 1977, McBride 1983, Moore 1974). Fire scars can be extremely useful for understanding the relationship of fire within the ecosystem both spatially and temporally (Guyette & Cutter 1991, Guyette & Dey 1995, Smith & Sutherland 1999, Swetnam & Baisan 1996). Fire scar dates can be analysed and converted

into time-since-last-fire data. This is used to estimate the fire cycle and fire frequency, which is useful for understanding the historical role of fire, predicting fire events, and reintroducing fire into ecosystems where fire suppression practices have eliminated fire from a particular landscape (Johnson & Gutsell 1994, Larsen 1997, Van Wagner 1978).

Hypothesis 1

Because the study area is located in the north-central boreal forest and has only recently been influenced by white settlers, the hypothesis for this study can be considered as three sub-hypotheses. The first sub-hypothesis is that the fire cycle was long and frequency was low before the fur traders arrived. The second sub-hypothesis is that the frequency increased and the cycle became shorter upon the arrival of the fur traders because of an increased number of human fire starts, and (third sub-hypothesis) once again lengthened and became less frequent with the establishment of the town of Fort Smith and fire suppression activities.

Chapter Two

Dendrochronology is the term that is used to describe the dating of events from tree rings, but more commonly it refers to techniques which link ring widths and modern meteorological records to create a proxy climate series (Fritts 1976). Arno and Sneck (1977) refined the methodology that is still used today for collecting tree samples, while dendrochronological methods have advanced significantly since the 1970s. While ring widths (which are biased towards early wood) have been used since the early 1900's, ring density has only relatively recently (1965) been shown to be valuable as well, particularly for latewood (Cleaveland 1986, Fritts 1976).

Reconstructing the paleoclimate or other event chronologies from tree rings is important in understanding the historical events that influenced the landscape. Correlating the reconstructed climate records with Fire Behaviour Prediction (FBP) components, specifically those of the Fire Weather Index (FWI), may be a practical method to predict fire events. Measurements of temperature, relative humidity, wind speed, and 24 hour precipitation are taken daily at noon local standard time during the fire season; these measurements are then

used to calculate FWI codes and indices which are an indication of potential fire activity (de Groot 1988, Hirsch 1996). The FWI system consists of three fire behaviour indices, the build-up index (BUI), initial spread index (ISI) and the fire weather index (FWI), and three fuel moisture codes (fine fuel moisture code (FFMC), duff moisture code (DMC) and the drought code (DC)). To be able to establish a relationship between the Fire Weather Index moisture components and tree growth would be extremely useful as these drought codes are the most common and familiar to fire practitioners.

Hypothesis 2

The vegetation immediately surrounding Fort Smith is dominated by *Pinus banksiana*, an extremely flammable fuel type that is susceptible to ignition any year. However, it is only during periods of severe drought that the wetland areas south of the community, the majority of the study area, are susceptible to ignition. It was hypothesised that the FWI moisture codes (DC, DMC, and BUI) from 1955 to 1995 could be correlated to tree ring series from 1770 to 1995 for the Fort Smith area. Three ring features were analysed: ring width to indicate a severe fire season, relative earlywood width, to indicate a spring fire season, and maximum latewood density, to indicate late season drought.

Chapter Three

Understanding the vegetation in a particular region is critical for predicting fire behaviour and managing fire (British Columbia Ministry of Forests 1994, Foster 1983, Hirsch 1996). Once the vegetation types are classified, fuel corridors and fuel breaks can be identified and the location of various lines of defence established. Remote sensed data (airphotos) are commonly used to analyse vegetation and to map the various polygons (British Columbia Ministry of Forests 1994, Johnson *et al.* 1990). Airphoto analysis is particularly useful in remote or large areas, the Fort Smith area being both remote and difficult to access. However, airphoto analysis must be accompanied by ground-truthed data; the study not only identified fuel corridors and breaks, but also compared ground-truthed data with the Alberta Wetland Inventory (AWI) system of vegetation classification (British Columbia Ministry of Forests 1994, Vitt *et al.* 1997).

Hypothesis 3

The Alberta Vegetation Inventory is the most commonly used classification system, while the Alberta Wetland Inventory is a relatively new system of classifying vegetation from airphotos. It was hypothesised that the AWI can be used to locate natural fuel breaks and corridors.

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Chapter 1
A Fire Event History of the Fort Smith, NT Area

Introduction

Fire cycle is defined as "the number of years required to burn over an area equal to the entire area of interest", while fire frequency is defined as "the average number of fires that occur per unit time at a given point". Finally, fire interval is defined as "the average number of years between the occurrence of fires at a given point" (Merrill & Alexander 1987). These are controlled by the climate, which directly affects fuel moisture and indirectly affects fuel type and anthropological activities (Johnson *et al.* 1990, Simard 1990). By determining the fire cycle and frequency, it is possible to gain an historical perspective of the role of fire and the impact of man in a particular landscape. Fire histories can be constructed by analysing fire scars, release growth in tree-rings, tree ages and historical records, and then mapping the data and plotting them as a negative exponential survivorship curve, the map and graph both illustrating the time-since-last-fire (TSLF) (Johnson *et al.* 1990, Johnson & Gutsell 1994, Johnson & Van Wagner 1985, Larsen 1997, McBride 1983, Merrill & Alexander 1987).

Fire scars, which generally appear as an upside-down V-shaped opening in the bark, result from either the heat of the flames destroying part of the cambium, or actual combustion of the bark, cambium, and xylem (McBride 1983). Over time, the bark is shed and the sapwood is exposed which increases the susceptibility of the tree to further scarring, often resulting in multiple scars (Boyce 1921, McBride 1983, Toole 1961). Tree-rings can also be examined for a sudden increase in ring width for a period of time (known as release rings) which may indicate a fire event, after which the survivor tree benefited from decreased competition (Henry & Swan 1974). Combining fire scar data with historical records of fire occurrences and suppression practices is useful, not just for establishing fire events, but also for mapping purposes (Heinselman 1973, McBride 1983).

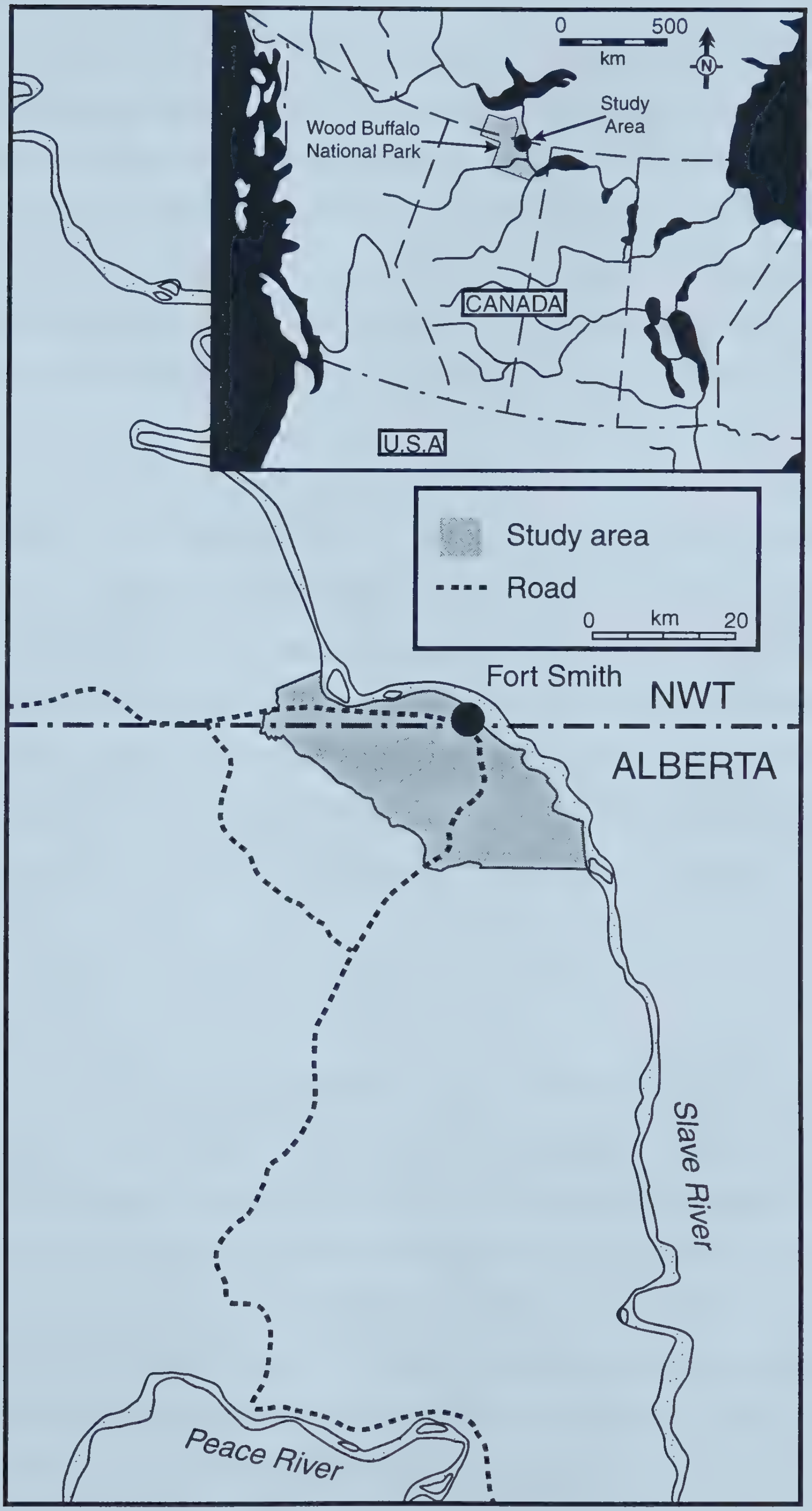


Figure 1. Location map of study area, southwest of Fort Smith, Northwest Territories (60° 00' N and 111° 55' W).

For the town of Fort Smith, NT the development of a fire management plan became important for a number of reasons (Anonymous 1995). The town is surrounded by a forest fuel type that supports intense crown fires (*Pinus banksiana*), is near Wood Buffalo National Park (WBNP) where fires could move toward the town (Larsen 1989), is close to the waste disposal area which could provide a potential source of ignition, and is near important timber and non-timber resources. The wish to find effective ways to protect the community, as well as the paucity of information on the landscape between the town and WBNP have contributed to the need to develop a plan to manage the surrounding forest and the threat of fire.

Because the study area is located in the north-central boreal forest and has only recently (circa 1874) been settled by white fur traders, it is hypothesised that the fire cycle and frequency before the fur traders arrived was comparatively long. The second hypothesis is that the frequency increased and the cycle became shorter upon their arrival because of more human-caused fire starts, and the third hypothesis is that the cycle lengthened and fires became less frequent with the establishment of the town of Fort Smith and fire suppression activities. To test this hypothesis a fire event chronology was developed for the past 225 years.

Study Area

The town of Fort Smith is located at 60°00' N and 111°55' W, just above the Northwest Territories/Alberta border, in Canada (Fig.1). Within the study area, the town of Fort Smith is located in the northeast corner (Fig. 2). The 595 km^2 study area is bounded by the Slave River on the north and east, the Salt River (which doubles as the Wood Buffalo National Park border) on the west, and the WBNP border on the south (1:50 000 topographic map sheets, 85 A/1, 75 D/4, 84 P/16, 74 M/13). There is one road which runs east-west, through the town, and another road which runs north-south, from the town to WBNP. There are many paths and a few old roads through the northern and eastern parts of the study area, but the majority of the area is not easily accessible.

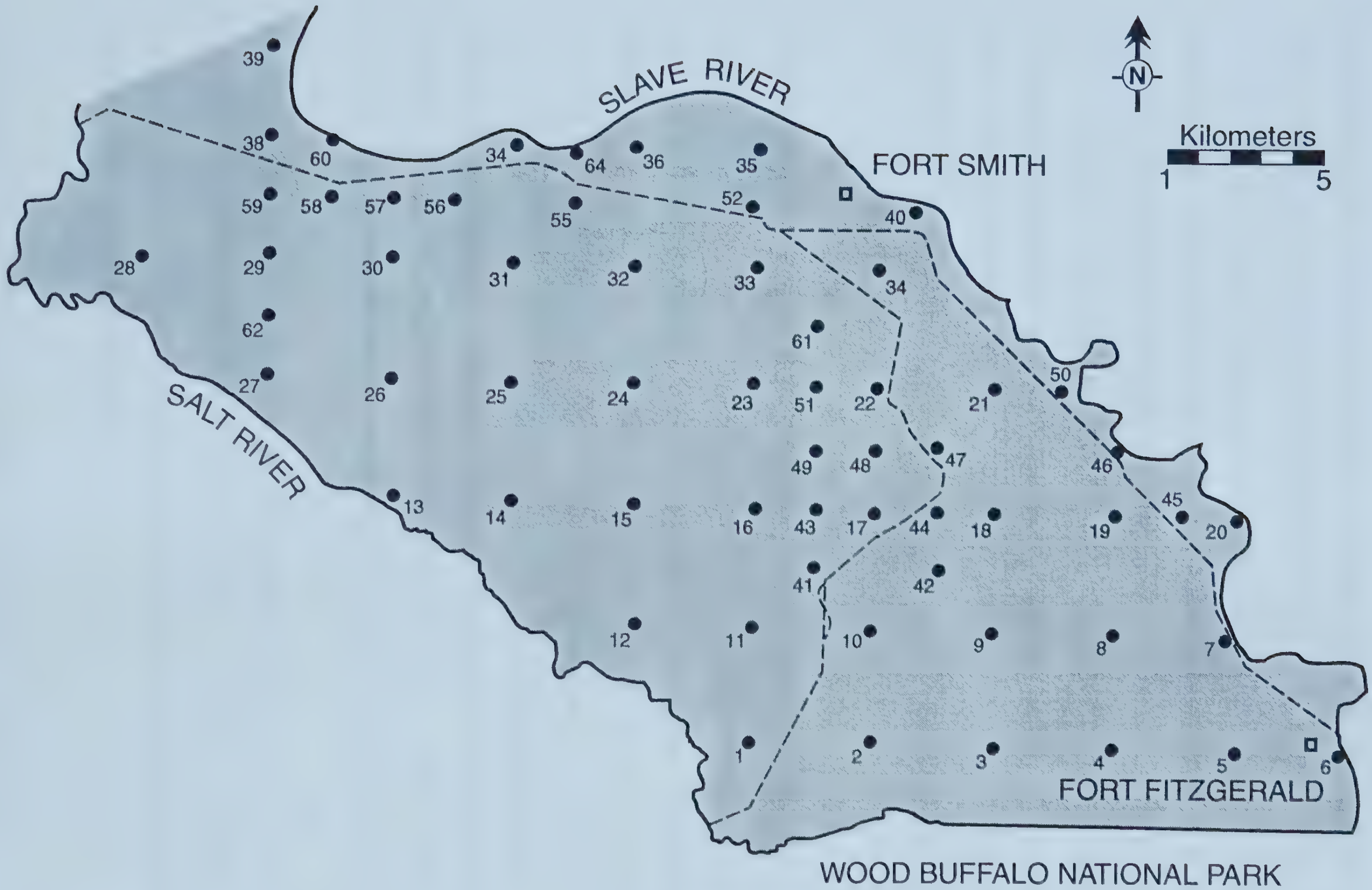


Figure 2. Sample points in the 595 km^2 area located between the Slave River and Wood Buffalo National Park and south of Fort Smith, (60° 00' N, 111° 55' W).

Geology

There have been some studies of the geology along the Slave River, but almost none specifically for the area around Fort Smith, with the exception of Craig (1963), Bentz *et al.* (1990), and Bednarski (1999). Two million years ago, in the Quaternary period, the study area was covered by the Pleistocene ice sheet. The Wisconsinan Glacier, part of the Laurentide Complex, retreated from northern Alberta approximately 10 000 years ago, resulting in the formation of Glacial Lake McConnell (Peterson *et al.* 1972, Prest 1970). The sill of Precambrian rocks just east of Fort Smith, where the Slave River currently flows, is the reason for the separation of Great Slave and Athabasca Lakes. When the water level in Glacial Lake McConnell dropped, the lower part of the Slave River valley became alluviated, resulting in the Slave River Lowlands, where the study area is located (Craig 1963).

Bednarski's (1999) study indicates that the surficial geology of the study area consists primarily of glacio-lacustrine deposits. The sediment is more than one metre in thickness, and in a small area just south of Fort Fitzgerald, is hummocky. A wide band of eolian deposits is evident along the Slave River and around some of the more distinct paleochannels. Some lacustrine deposits can be found around and south of Four Mile Lake (a large lake just south of Fort Smith), generally around the paleochannels. Finally, two types of till were observed; till blanket on the southern border of the study area, between the Slave and Salt Rivers, and till veneer along the Salt River. Unfortunately, there is no specific data in any of the studies concerning the western side of the study area.

As for bedrock geology, there is even less information than on the surficial geology. According to Reid, Crowther and Partners Ltd. (1982) a continuum exists from east to west, with Precambrian rock being most common at the Slave River (the east), and paleozoic rock becoming more frequent to the west.

The topography of the region is extremely flat, with the exception of the areas along the Slave River.

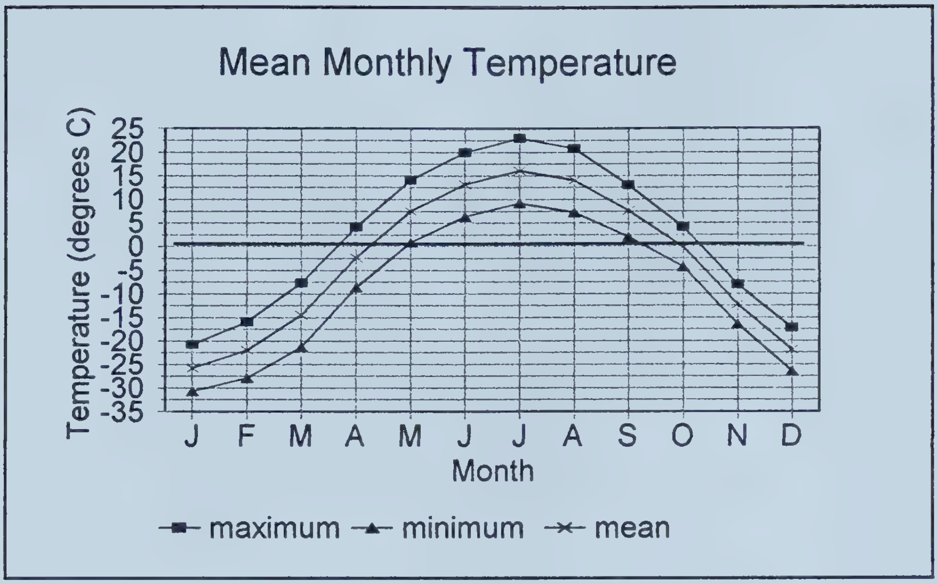
One other feature of the study area is that it falls within the region of discontinuous permafrost, and there is evidence of pockets of permafrost throughout the study area.

Climate

The Fort Smith area has a continental climate with mean annual temperature of -3.4°C. This is because winters are quite long and cold, dominating the year, while summers tend to be short, hot and dry (Fig. 3): the summer-winter extremes can be as much as 96.6°C (Table 1). The majority of the precipitation (mean annual precipitation: 351.0 mm) falls in summer in the form of rain, with an annual average of 212.7 mm (Environment Canada file).

In terms of fire weather, the study area falls into zone 5 (there are 7 zones in Canada) (Simard 1990). This means that within a fire season fires will be potentially uncontrollable with occasional conflagrations and fire storms developing for 3% of the days; these intensity levels are likely to be reached in each fire season. As for the remaining 97% of days in the fire season, little or no action will be required for 15% of the days and minimal control is required for 40% of the season. Light surface fires are likely to occur on 10% of the days, moderate to high intensity surface fires for 25% of the days; and torching out is likely to occur for 7% of the fire season.

In terms of fire starts, the study area can be divided into two zones. The zone north of the 60th parallel and east along the road (Fig. 1), experiences primarily anthropogenic ignitions as these areas are dry, easily accessible to humans, and the waste disposal area is ignited numerous times every year (Renewable Resources staff, *pers. comm.* 1996). The area south of the 60th parallel and west of the road is dominated by wetland and there is little human activity in this zone. As a result, lightning is the primary source of ignition in this zone (Renewable Resources maps). Viewing the study area as a whole, however, the majority of



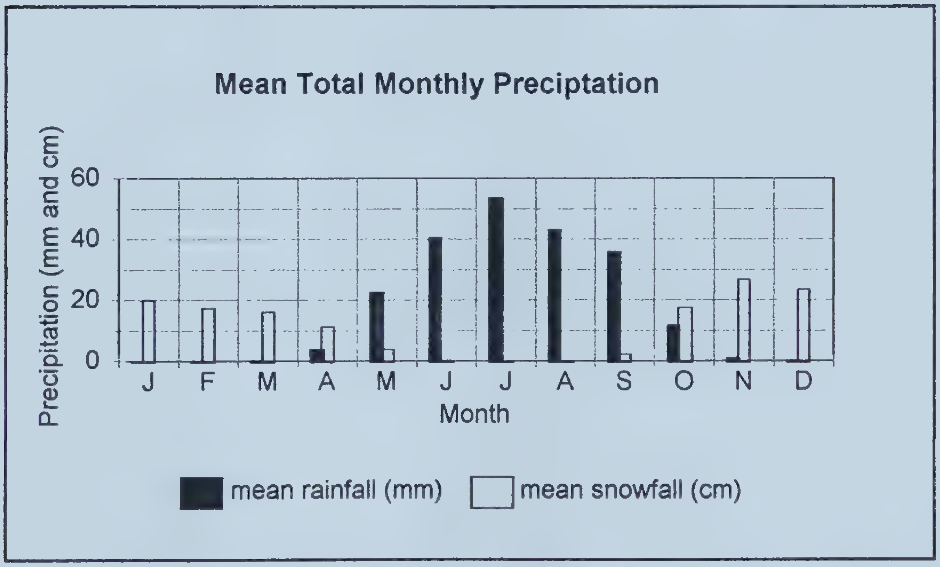


Figure 3. Mean monthly temperature and precipitation for Fort Smith, NT, calculated from daily data over 77 years (1915-1991). Daily data from Environment Canada.

TEMPERATURE		PRECIPITATION	
Extreme Maximum	39.4°C	Extreme Annual Maximum	617.7 mm
Extreme Minimum	-57.2°C	Extreme Annual Minimum	145.9 mm
Mean Annual Temp.	-3.4°C	Mean Annual Precipitation	351.0 mm
Mean Daily July Temp.	15.9°C	Mean Annual Rainfall	212.7 mm
Mean Daily January Temp.	-25.0°C	Mean Annual Snowfall	138.4 cm

Table 1. Precipitation and temperature data for the Fort Smith, NT region from 1915-1995.

fire starts are anthropogenically caused and occur in the most volatile fuel type (jack pine) which also corresponds to the area where the most values-at-risk are found.

Vegetation

Broadly, there are three types of vegetation in the study area (Map 1). Above the 60th parallel, the dominant vegetation is *Pinus banksiana* (jack pine). Along the western boundary, following the Salt River, is another upland region, dominated primarily by *Populus tremuloides* (trembling aspen). The remainder of the area is comprised of a variety of wetland types. Treed fens are the most common, with varying amounts of *Picea mariana* (black spruce), *Betula glandulosa* (dwarf birch) and *Salix* spp. (willow). Almost at the centre of the study area, and towards the boundary with WBNP, graminoid fens dominate.

Historical Land Use

The region was inhabited by the Slavey, Beaver, Tutchone, Dogrib, Hare, Caribou and Chipewyan, and later the Cree First Nations. There is very little information on the activities of these groups in the Fort Smith area; specifically, there is little information on their relationship with fire. Both the Hudson's Bay and the Northwest Companies were attempting to establish fur trading forts beyond the Hudson Bay and in 1874 Fort Smith was founded by the Northwest Company, at the end of the portage around three sets of rapids on the Slave River (Fort Fitzgerald was established at the head of the rapids). Soon after the establishment of Fort Smith, steamboat construction began, and a total of seven boats were built during the period of 1884-1902. Because of the steamboat industry, many trees along the shores of the Slave River were cut down during this period. The population at this time was approximately 158 (Green *pers. comm.* 1995).

The fur trade peaked around 1920, and there were 118 fur traders in Fort Smith that year. In 1922, WBNP was created to protect 500 Wood Bison and in 1929, an airport was built which provided another route into the community, other than the river. However, it was the CANOL pipeline project which had the most impact on the area in terms of development. In 1942, when the population of Fort Smith was only 250, 1 500 U.S. troops arrived to

transport materials for an oil refinery at Norman Wells and for a 1 300 km pipeline from Norman Wells to Whitehorse. Besides working on the CANOL project, the troops improved the infrastructure of and access into the community by, among other things, constructing a road connecting Fort Fitzgerald, Fort Smith, and Hay River (Green *pers. comm.* 1995). After this period, the settlement was firmly established and people moved in from the bush to live in town. Interest turned from making a living from the land towards municipal and territorial development, and today the community's population is approximately 2500 (Green, *pers. comm.* 1995).

Fire Records

In terms of known fire history, only one fire is recorded: according to Delisle and Hall (1987), a large fire burned almost a third of the study area, mainly the southeastern corner, in 1953. No other large stand-replacing fires before that time have been recorded, and none have occurred since then (Delisle & Hall 1987). This is not to say that there have been no fires in this area. In fact, there have been numerous fires at the waste disposal area, and there is evidence of fire throughout the study area, but the former were too numerous and the latter were too small to be recorded. Fires that have occurred within the study area since the Town was established have generally been immediately suppressed.

METHODS

a) Field

As historical fire records only span the last forty-eight years, fire scars were used to determine the fire cycle, frequency and interval for the Fort Smith area for the past 225 years. Dating of fire scars can be used to estimate time-since-last-fire (TSLF) and the TSLF data were used to estimate fire cycle, frequency, and interval (Johnson *et al.* 1990, Larsen 1997, McBride & Laven 1976).

In order to obtain data for the fire and drought chronologies as well as to complete the ecological assessment, a stratified grid approach was used. Using a four-kilometre grid, random points were identified on topographic maps at 1:50 000 and then located in the field

using a Global Positioning System (GPS). Because a higher sampling intensity was required in coniferous areas in order to establish an accurate picture of the historical role of fire and the history of drought within the landscape, a two-kilometre grid was used in this vegetation type (Arno & Sneck 1977, Houston 1973, Zackrisson 1977). Broad scale units of vegetation types were identified from 1987 air photos.

The grid system was selected for a number of reasons: 1) as a basis for random sampling; 2) because of the difficulty in discerning even recent (1953) burned margins on air photos due to high landscape heterogeneity; 3) because of limited accessibility, as there are few roads and the region is predominantly wetland; and 4) because trees were rare within graminoid or open fens, and fire scarred trees are more common in treed fens and upland areas. The grid system allowed the sample points on the topographic maps to be identified by converting UTMs to GPS points, and then located using the GPS on the helicopter and a hand-held GPS unit. Almost half of the 62 sites were accessible only by helicopter, while the other half were accessible by a combination of automobile and foot.

At each site at least one tree was sampled by removing a cross-section and ecological data were recorded. The oldest, healthiest, non-fire-scarred tree was sampled to facilitate cross-dating (Arno & Sneck 1977). Since fire scarred samples are required to determine fire cycle, frequency, and interval, stem cross-sections were removed from the largest trees with external fire scars (Arno & Sneck 1977, Johnson & Gutsell 1994, McBride 1983). Because jack pine is a volatile fuel type that is susceptible to scarring, fire scarred trees were observed only in jack pine stands. Additionally, either the entire stand showed no evidence of fire, with the rare exception of some survivor trees, or the majority of trees were scarred, and no large unscarred trees were available for sampling (Gauthier *et al.* 1996). Trees were sampled just above the root swell to obtain as long a record as possible and to prevent distortion of the rings, that is, to ensure that the xylem was vertical for the digital analysis of the rings with DendroScan (Varem-Sanders & Campbell 1996). Tree discs were then allowed to dry gradually at room temperature before they were prepared for analysis.

b) Laboratory Methods

i) Dating Fire Events

The tree-discs were sorted into two groups, fire-scarred and non-fire scarred, and analysed separately. Once the fire-scarred tree discs were air-dry, one side of each disc was sanded using both belt and palm sanders with increasingly finer grit paper (from 30 to 600 grit). The rings were then hand counted, compared, and fire scars dated. Non-fire scarred samples were processed by first reducing the tree-discs to radii, generally two per sample, along a diameter. The radii were then subsampled using a thin slicing method before being subjected to both chemical and water extractions to remove organic and inorganic substances in the xylem. Once the extractions were complete, the subsamples were dried, pressed, X-ray photographed and finally digitally analysed using Dendroscan (Varem-Sanders & Campbell 1996). The digital analysis provided estimated tree age data, and for jack pine (because of their serotinous cones and germination requirements), estimated stand age (Gauthier *et al.* 1996).

ii) Estimating TSLF

Estimated time-since-last-fire (TSLF) was determined by using a combination of fire scar dates and tree ages (Johnson & Gutsell 1994, Larsen 1997, Varem-Sanders & Campbell 1996). The estimated stand ages as well as the latest fire scar dates were placed into fifty-year age classes and mapped, while the estimated TSLF data were graphed in ten-year age classes on a semi-log scale, and submitted to regression analysis. Average fire interval was estimated by calculating the mean between estimated year of establishment of jack pine trees and the first fire scar, and the mean interval between consecutive fires (Johnson & Gutsell 1994).

RESULTS

a) Fire Event Chronology

Based on the fire scar evidence, there were at least forty-six fires in the study area between 1770 and 1995, a 225-year period (Fig. 4). The 10-year interval with the most number of fires was 1940-1949, with 15 fires, while the interval with the second highest number of fires was 1870-1879, with 7 fires. Before 1869, fire scar evidence indicates only occasional fires, with only three fire scars available for the period between 1770 and 1869. The fire event chronology was based exclusively upon fire scars, which were found only in *P. banksiana* sites. Although *P. banksiana* grows primarily in the area north of the 60th parallel, it can be found as small islands, less than 50 m in diameter, throughout the study area. Because of the distance between sampling sites (2-4 km) and the heterogeneity of the landscape, it was not possible to confirm whether or not fire scars of the same year belonged to the same fire (Map 1). Therefore, each fire scar was viewed as an independent fire event.

b) Time Since Last Fire Map

The time-since-last-fire (TSLF) map indicates that the majority of sites (at least 48 of 62) have had a fire within the past hundred years and in the southeast corner of the study area, near Fort Fitzgerald, there was evidence of a large stand-replacing fire within the past fifty years (Fig. 5). Only the area near the Salt River shows no evidence of fire within the past 225 years. The study area, despite being located in the boreal forest where large fires occur and therefore generally produce large homogenous areas, is very heterogeneous (Map 1) (Bergeron 1991, Van Wagner 1983). Because of the high landscape heterogeneity it is impossible to extrapolate the TSLF data beyond the sample points, or even to determine if same-aged scars or stand ages are the result of one fire or numerous small fires.

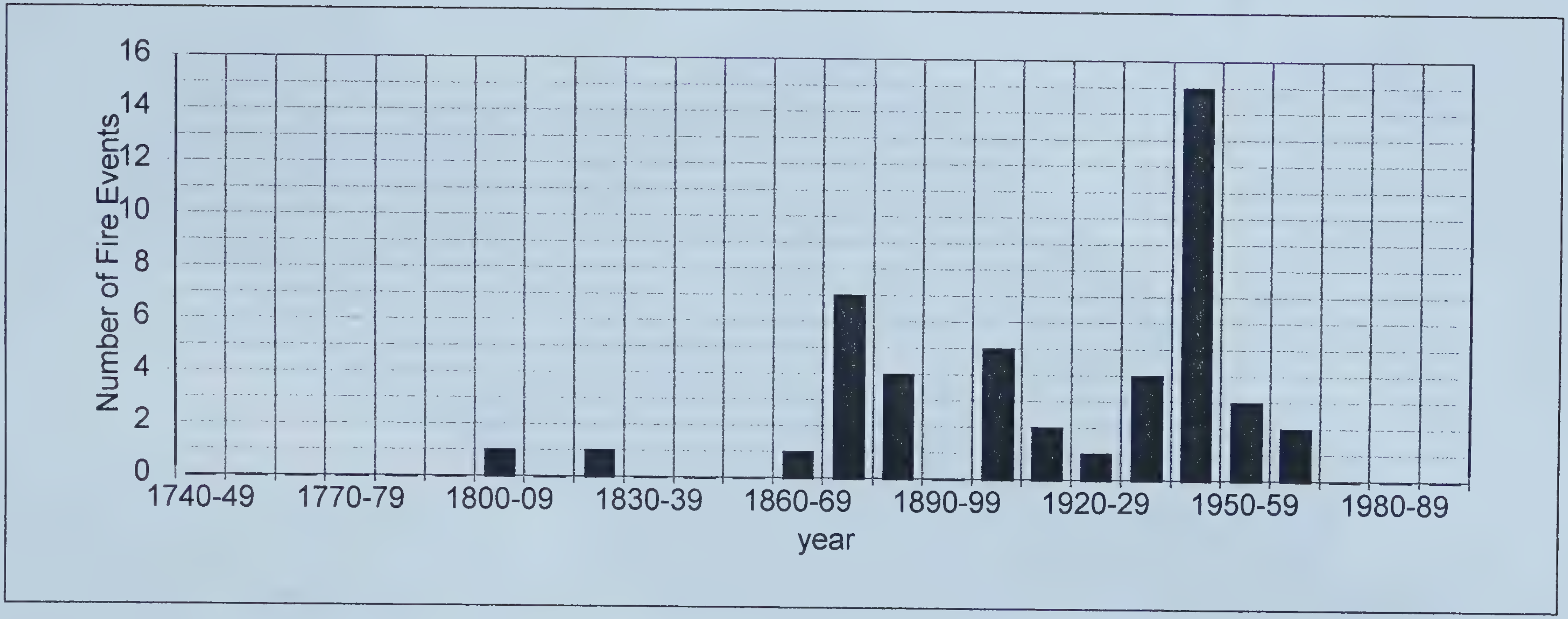


Figure 4. Fire events, by decade, near Fort Smith, NT. Fire Events based on fire scars.

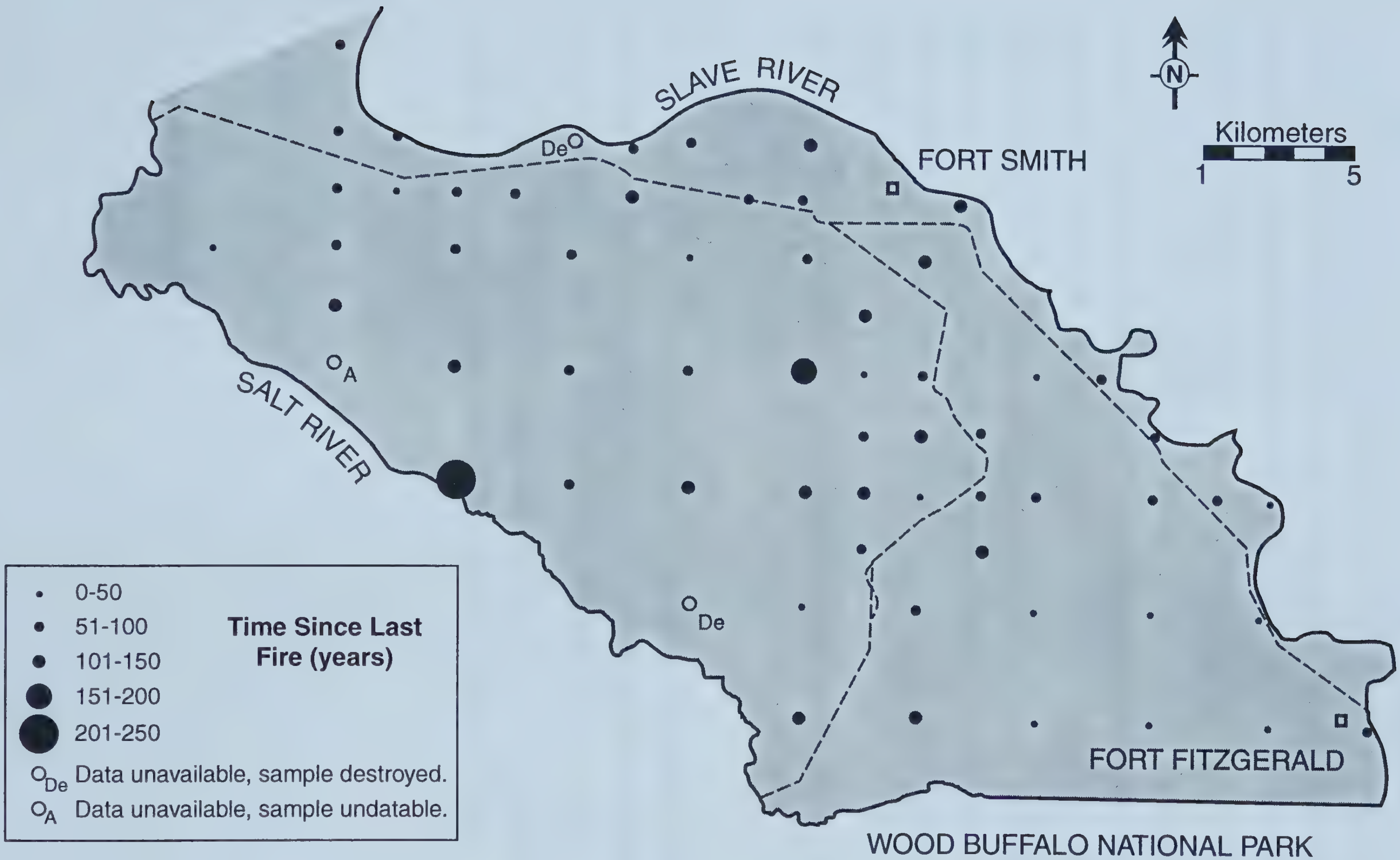


Figure 5. Estimated time since last fire map, in 50 year intervals, for the Fort Smith, NT area sample points.

c) *Time Since Last Fire Graph*

The estimated TSLF data, in 10 year intervals, was plotted on a semi-log scale and analysed using a regression line, the slope of the regression line being equal to the fire frequency of the study area, and the inverse being equal to the fire cycle (Fig. 6) (Johnson & Gutsell 1994, Larsen 1997). The graph shows two breaks in the curve, which indicates three regimes over the 225-year period and is referred to as a mixed distribution (Johnson & Gutsell 1994). For the earliest period, 1865-1895, the fire cycle was estimated at 181 years, and the frequency at 0.55%. The second period, 1895-1935, has a longer estimated cycle of 267 years and a lower frequency of 0.38%. Between 1935-1945, the fire cycle shortened to 29 years and the frequency was 3.40%. After 1945 the estimated frequency decreased to 0.77% and the cycle lengthened to 130 years. This mixed distribution, indicated by the change in slope, is the result of either "spatially distinct landscapes with different fire frequencies" or "temporal changes in fire frequency" (Johnson & Gutsell 1994). Because of the low number of fire scars before 1865, the period between 1775-1865 was not analysed.

d) *Fire Interval*

The fire interval, the average number of years between the occurrence of fires at a given point, was estimated from the fire-scarred samples, that occurred exclusively on jack pine trees (Larsen 1997, Merrill & Alexander 1987). Based on the fire scar data, the estimated average fire interval within the jack pine sites is 40 years between the date of establishment and the first fire, and the average interval for consecutive fires is 37 years.

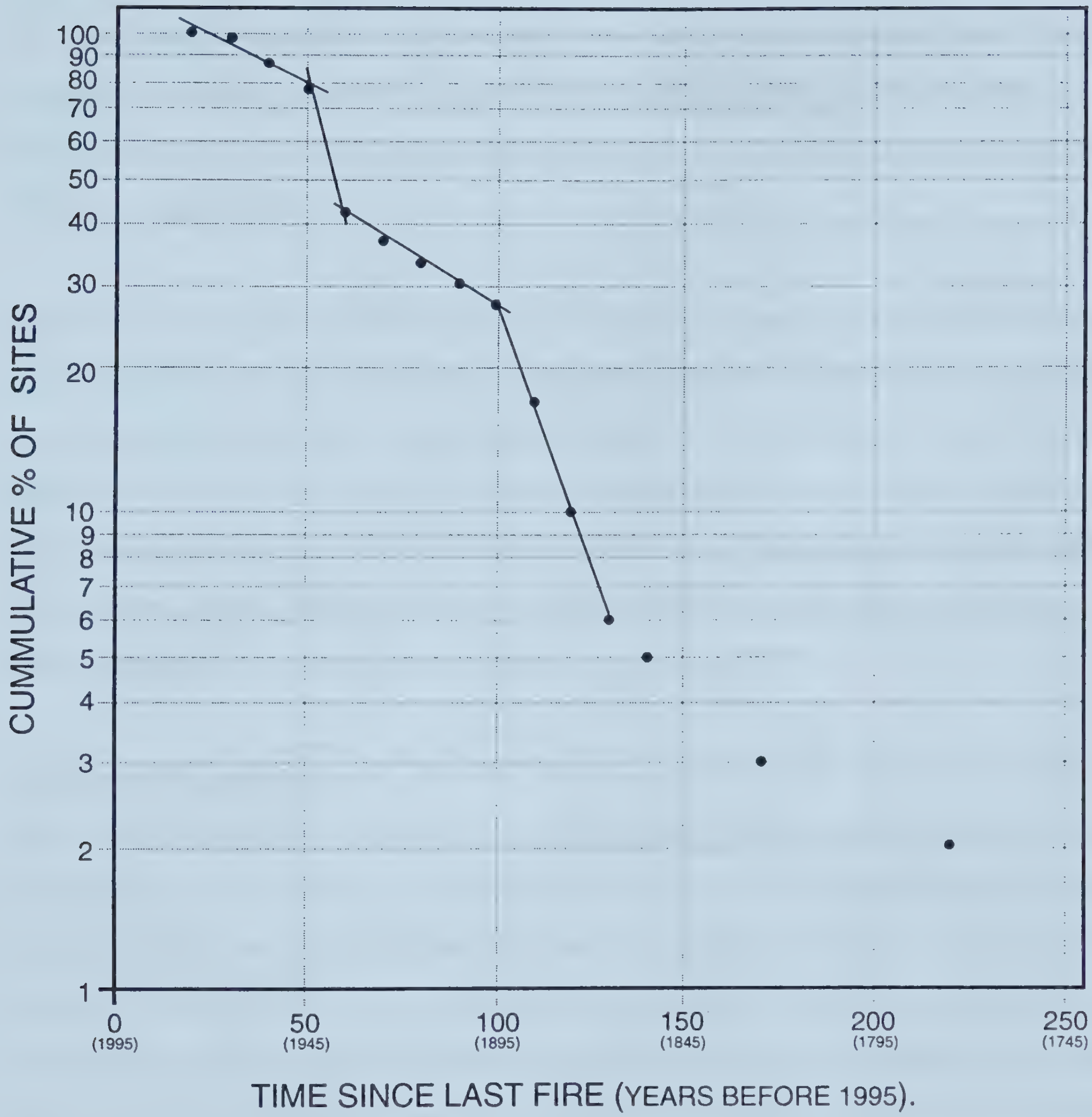


Figure 6. Estimated time since last fire graph, in 10 year age classes, for the Fort Smith, NT area sample points, plotted on a semi-log scale. Slope of the lines on the graph indicates fire frequency and the inverse of the slope (1/slope) indicates fire cycle. The fire cycle since 1945 is 130 years. From 1935 to 1945 the fire cycle was 29 years, between 1895 and 1935 the fire cycle was 266 years, and between 1865-1895 it was 181 years. Based on fire frequency calculations, 0.77% of the study area burned annually since 1945 and between 1935 and 1945, 3.40% burned annually. Only 0.38% burned annually between 1895-1935 while 0.55% of the area was burned between 1865-1895.

Discussion and Conclusions

a) Number of Fires

The fire event chronology indicates that there were numerous small fires (forty-six) throughout the study area over the past 225 years, and appears to confirm the lack of a large stand-replacing fire, with the exception of the 1953 fire in the same 225 year period (Fig. 4) (Delisle & Hall 1987).

Based on the jack pine fire scar evidence, the two 10-year periods with the most number of fires were 1870-1879 (with 7 fires) and 1940-1949 (with 15 fires) (Fig. 4). In examining the anthropogenic history, these two periods correspond with significant occurrences in the study area. In 1874, the Fort was established, and the concentration of human activity in the area likely resulted in an increase in the number of fires. The second period, which has the most number of fires, coincides with the arrival of U.S. troops and the expansion of the small settlement into a larger town (Green, *pers. comm.* 1995).

b) Fires by Vegetation Type

The two dominant tree species in the area are jack pine and black spruce. Jack pine is found primarily in the part of the study area that falls above the 60th parallel, and forms small stands on open dune sites throughout the rest of the study area (Desponts & Payette 1993) (Map 1). Arno (1980), in examining lodgepole pine stands (lodgepole and jack pine trees being closely related), found that "ground fires of low to medium intensity were common" in these stands and that pine trees were extremely susceptible to scarring, due to the high levels of resin and the xeric habitats where they were found (Bergeron 1991, Verral 1938). Thus, because of landscape heterogeneity combined with the distance between jack pine islands, it is possible that many of the forty-six fires are in fact independent of one another.

Although jack pine is found throughout most of the study area, the landscape is dominated by wetland, specifically treed fens, where the dominant tree species is black spruce (Map 1). Bergeron (1991) found that spruce woodlands have almost no fire scar evidence, which is also the case for the Fort Smith area, as "[t]he thick mat of mosses under sparsely distributed

spruce trees helps to retard fuel drying and decrease fire susceptibility." This, in combination with the fact that low intensity fires do not always wound, even for previously scarred trees where resin is exuded, emphasises that fire scarring is only one type of fire evidence and may not provide a completely accurate fire history (Arno 1980, Bergeron 1991, Verral 1938).

There is no direct evidence of fire in the area dominated by *Populus* near the Salt River. Although this indicates that the Salt River and the vegetation surrounding it serves as a natural fuel break, specifically from fires moving north-east from WBNP, it is possible that fires have occurred in this area, but that there is simply no fire scar evidence. The Slave River serves as a fuel break for fires moving southward, however the area just south of the river tends to be dominated by jack pine where there is a substantial amount of fire evidence.

c) Fire Cycle and Frequency and Interval

To develop the fire history further, the estimated time-since-last-fire (TSLF) data were also examined, which included estimated tree/stand ages in addition to fire scars (Johnson & Gutsell 1994, Larsen 1997). Based on the evidence collected, the second sub-hypothesis that the fire cycle was shorter and the frequency higher during the development period of the Fort compared to the pre and post fur trade periods is incorrect. While the arrival of fur traders in the area is associated with a higher fire frequency and a shorter fire cycle, the establishment of the town (third sub-hypothesis) did not lower the incidence of fire, rather the cycle became shorter and the frequency increased.

For the earliest period (1865-1895) (first sub-hypothesis), the estimated fire cycle is only 181 years while the frequency is estimated at 0.55%. These data are somewhat deceptive because the area was burned in 1953 by a large stand-replacing fire, which would have removed many trees carrying fire evidence. Additionally, the deadwood has decomposed substantially due to the raised water level from melted permafrost and decreased evapotranspiration (Smith & Sutherland 1999). However, the data from the start of this period, 1865, is consistent with a change in fire regime observed in eastern boreal forests,

where the tree records are longer (Gauthier *et al.* 1996)

The period from 1895-1935 (second sub-hypothesis), had the longest estimated fire cycle and lowest fire frequency, at 267 years and 0.37 % respectively (Fig. 6). This frequency and cycle matches with the data from WBNP (Larsen 1997); however, the data for Fort Smith is for a shorter time span. Since this regime (1895-1935) is consistent with the data from WBNP and the landscape of the study area appears to be a continuation of the landscape in the Park, the differences in fire regime for the study area are likely due to factors unique to the study area, specifically the large stand-replacing fire of 1953 and the greater anthropogenical influences.

Between 1935-1945, the fire cycle shortened and the frequency increased dramatically, to 29 years and 3.40% respectively. This change in fire regime is likely linked to increased human activity in the area, specifically the arrival of the 1 500 U.S. troops in 1942. The increased population and activity in the area is the likely reason for the short fire cycle and high frequency.

Once the troops departed, the fire cycle and frequency decreased to 130 years and 0.76% respectively for the period of 1945-1995. Although the population today exceeds the 1942 level, human activity has become more concentrated around the community, and methods of fire detection and suppression are well in place. Since neither of these two periods are observed in WBNP where human impact has been less than in the study area, this difference is likely due to anthropogenical influences. Therefore, the estimated TSLF data indicate that the fire cycle was long and the frequency low when the community was very small, and that since 1935 the incidence of fire increased as the town of Fort Smith expanded from a settlement into a town.

The fire cycle data for the Fort Smith area is inconsistent with data for other parts of the boreal forest, where the cycle is commonly observed at 50-60 years. Not surprisingly, the fire interval is very similar to that of the adjacent area of WBNP (Larsen 1997). While

WBNP has a 42-year average interval between the year of establishment and the first fire, it is 40 years for the Fort Smith area. The fire interval for consecutive fires is again slightly higher in WBNP than in the Fort Smith area, at 40 and 37 years respectively.

d) Effects of the 1953 Fire

This study confirms Clark's (1989) study of disturbance events, which challenged two assumptions; that the disturbance process is stationary (environmental stationarity) and that the probability of disturbance does not change with time since the last disturbance (constant hazard assumption). Clark found that the probability of fire occurrence increased with the time since last fire. Additionally, "the site occupants themselves may contribute to disturbance probability and magnitude: disturbance probability may change with time since the last disturbance as the biota modifies local conditions." This generally refers to the theory of fuel build-up over time, but since recovery from disturbance of boreal vegetation is slow, the lack of biomass as a result of a significant fire event can cause the melting of permafrost, a reduction in evapotranspiration, and therefore an increase in soil moisture which will also modify local conditions (Eastwood *et al.* 1998). Both the accumulation of fuel as well as the increase in soil moisture can be observed throughout the study area, the increase in moisture most commonly observed in the southeastern part of the study area which was burned in the fire of 1953 (Map 1).

e) Influences on Fire Scar and Stand Age Data

The difficulties encountered with the fire scar and tree/stand age data for this study area are due to a number of factors, including tree species, short-lived trees, high degree of landscape heterogeneity, the large stand-replacing fire of 1953, and the number of sample points. While pine exhibits a high degree of fire scarring, which "suggests that pine woodlands are more susceptible to fire than other fuel types", spruce trees scar less frequently due to the lower levels of resin and the habitat in which they are usually found (Bergeron 1991). Of the 107 trees sampled, only 4 originated prior to 1860, and the oldest was only 225 years. This is, however, consistent with the lodgepole trees sampled by Arno (1980) that had scars dating back only 200-225 years. The landscape heterogeneity, in combination with the

number of sample points (specifically the 2-4 km distance between points), means that the data cannot be confidently extrapolated. That is, the assumption that fires of the same year belong to the same fire cannot be made, this last factor being further confused by the occurrence of local ignitions at the waste disposal area. Finally, the large stand-replacing fire of 1953 which burned nearly one-third of the study area, according to the maps of Deslisle and Hall (1987), is partly obscuring the early fire history of the study area, as it leaves only a small area with older fire dates (Johnson & Gutsell 1994).

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Chapter 2
A DROUGHT CHRONOLOGY FOR THE FORT SMITH, NT AREA

INTRODUCTION

"Regional climate controls the frequency of fire in coniferous forest ecosystems by affecting the fuel moisture content and the probability of lightning. Indirectly climate also determines the fuel type and the rate of decomposition" (Johnson *et al.* 1990). Because the effects of regional climate over time are revealed through the analysis of tree-rings, the information contained within tree-ring series can be used as "proxy data to reconstruct past climates" and therefore past fire weather (Archambault & Bergeron 1992).

Typical dendrochronological studies link tree-rings to meteorological data for the purposes of extending meteorological records back in time. "The accepted method for establishing connections between climate and radial growth is based on the statistical comparison of growth ring chronologies (either in the form of raw ring-widths, indices, or maximum latewood densities) with series of meteorological data (usually monthly rainfall and mean monthly temperature figures)" (Bridge *et al.* 1996). However, in the boreal forest where fires tend to be large and frequent, linking tree growth to fire weather may also be useful. Being able to predict drought and therefore predict fire behaviour is important as it is "only during certain fuel-moisture conditions [that] larger fires [are] possible" (Johnson *et al.* 1990).

Fire weather, specifically the probability of fire starts, is assessed in Canada with the Fire Behaviour Prediction (FBP) system, the Fire Weather Index (FWI) being one part of that system (de Groot 1988, Hirsch 1996). The FWI is calculated from daily meteorological data as well as additional data specific to the area in terms of fuel depth and type; four of its codes and indices pertain specifically to moisture. The drought code (DC) is calculated from temperature and precipitation data, the duff moisture code (DMC) indicates the amount of moisture just beneath the top litter layer, the build-up index (BUI) is a combination of both the DC and the DMC, and the fine fuel moisture code (FFMC) indicates the amount of

moisture in the surface layer of fuels. Because of the wide fluctuations of the FFMC from day to day due to the short lag time, this code is not useful in creating a proxy fire weather series. Since the potential for fire activity is linked to the FWI, moisture codes that reflect potential drought conditions (the DC, DMC, and BUI) will be used to define drought, or critical fire weather, in the Fort Smith area.

Few pyrodendrochronological studies have been carried out in the Canadian boreal forest and even fewer have connected fire weather with tree growth; Archambault and Bergeron (1992) carried out their study in the Quebec boreal forest while Larsen and MacDonald (1995) worked in Wood Buffalo National Park. Both of these studies considered one tree ring variable, namely ring width, and only utilised the DC from the FWI system. Archambault and Bergeron (1992) found that their series, dating from 1292, had a strong relationship with the DC, while Larsen and MacDonald examined the relationship of DC to annual area burned, and found that the correlation was slightly higher in the previous year than the current year. They also found that "the DC in the current year was not significantly correlated with the standard or residual [ring width] chronology from any site." This study, however, will analyse whether the other components of the FWI besides DC (the DMC and BUI) can be linked to tree growth.

Tree growth involves both the ring width and density. Although there has been a significant amount of research linking tree-ring widths to climatic variations since the early 1900's, it has been only in the last few decades (since 1965) that maximum latewood density has emerged as another important variable in dendroclimatological studies (Briffa *et al.* 1998, 1990, Cleaveland 1986, Conkey 1979, 1986, Schweingruber 1988, Schweingruber *et al.* 1978). While ring width is often biased towards earlywood, which indicates early season conditions, maximum latewood density can be used to examine climatic conditions towards the end of the growth season.

Therefore, this study will examine the relationship of tree growth (specifically ring width, earlywood width, relative earlywood width as well as maximum latewood density) with fire

weather (specifically, the DC, DMC and the BUI of the FWI). This linkage is particularly significant for the Fort Smith area because the vegetation immediately surrounding the town is dominated by *Pinus banksiana*, an extremely flammable fuel type that could ignite any year. The area south of the community, however, is dominated by wetlands that would be susceptible to ignition only during periods of severe drought. It is hypothesised that the FWI moisture codes (DC, DMC, and BUI) will be correlated to tree ring series (ring width, earlywood width, relative earlywood width, and maximum latewood density).

METHODS

a) Field Methods

A stratified-grid approach was used to identify sites within the study area. Using a four-kilometre grid, points were identified on topographic maps at 1:50 000 and then located in the field using the helicopter GPS. Stratified sampling points were established by interpreting broad scale units of vegetation types from 1987 air photos and identifying coniferous vegetation in order to increase the sampling intensity within the treed vegetation type. This was necessary because of the high degree of heterogeneity in the landscape and because the area south of the community is dominated by wetlands. Within the coniferous vegetation type, a two-kilometre grid was used (Arno & Sneck 1977, Houston 1973, Zackrisson 1977). A total of 62 sites were identified, half of the sites being accessible only by helicopter, while the other half were accessible by a combination of automobile and foot.

At each site several trees were cored and their rings hand-counted to determine the oldest trees at the site. Once the oldest, healthiest, non-fire scarred tree was identified, a cross section was removed for the purpose of cross-dating, and ecological data (plant species and percent cover, amount of available fuel, depth of water, soil type and depths, slope, etc.) from the site were recorded (Arno & Sneck 1977). Where fire scarred trees were observed, exclusively in jack pine stands, the majority of trees exhibited scarring, and therefore no unscarred trees were available (Gauthier *et al.* 1996). The trees were sampled just above the butt swell to obtain as long a record as possible and to ensure that the xylem was vertical for the digital analysis of the rings with DendroScan. Tree discs were then allowed to dry

gradually before they were prepared for analysis (Varem-Sanders & Campbell 1996).

b) Laboratory Methods

i) Tree-Rings

Narrow ring width has most often been used to identify drought years, but density can also be useful, particularly for late season droughts. DendroScan, a computer software application, is capable of analysing both ring width and density. The basic steps followed in preparing the samples for digital analysis by DendroScan were those outlined in the DendroScan manual, which essentially involved thin slicing, extraction, X-raying, scanning and marking, and finally importing into the DendroScan application (Varem-Sanders & Campbell 1996).

Each tree disc was reduced to two radii (from opposite sides of the tree) which were adjusted to ensure that the cells of the xylem were as vertical as possible before the thin slicing procedure was carried out (Fritts & Schatz 1975). The radii were then subsampled using the thin slicing method, resulting in slices approximately one centimetre wide and exactly 1.45 mm thick.

For both the water and chemical extractions, the subsamples were laid out on a sheet of open weave nylon cloth, twenty centimetres wide, which was then rolled up, and the ends secured with string to prevent any small pieces from falling out. The samples were subjected to the first of two extractions by placing the nylon cylinder into a hot water extraction flask and allowing hot tap water to run for twenty-four hours, removing inorganic salts and water soluble resins. To clean the samples further, aliphatic and aromatic resins were removed with an organic solvent extraction. After eight hours the solvent extraction was complete and the subsamples were placed upon blotting paper, pressed between two curved steel sheets to ensure that every part of the sample would be equidistant from the X-ray source, and were then placed in the oven to dry for 72 hours.

On smaller, lighter, more manageable aluminium sheets, 5 x 7-inch pieces of acetate were laid down, and six to 10 subsamples arranged over top of it. Space was left at the top of the film for the calibration wedge (with known density) and lead labels, both of which were placed upon the acetate just before the X-ray photograph was taken.

The negatives were scanned into the computer at 1200 dpi and a digital black line, one pixel wide, was drawn perpendicular to the tree-rings for each subsample using Adobe PhotoShop. Once the pathways on all subsamples for each negative were complete, the TIF file was exported into DendroScan and converted into an ISC file where the digital pathway was read and translated. The output includes the identification and counting of rings, as well as ring width and density data. Each sample was then examined and edited where necessary, for example by removing false rings. The samples were then cross-dated, and the clearest, strongest samples selected for the master chronology.

Approximately 107 samples were taken from the field and analysed. Because many of the sites had been burned, nearly half of the tree samples were fire scarred. Those that were not scarred (68 samples) were examined for other perturbations that justified exclusion. The criteria for sample inclusion in the drought chronology was a minimum 30-year record with no fire scarring, release rings or any other perturbations. Out of 68 trees, 29 fit the criteria. Tree-ring variables from each of the master chronology samples were imported from DendroScan into Excel: ring width; earlywood width; relative earlywood width; and maximum latewood density. Ring width was selected to identify a dry year, while the earlywood and relative earlywood widths were selected for early season droughts. To examine late season droughts, maximum latewood density was used. The raw data from each sample were detrended, converted into an index, and the indices averaged for each site (Fritts 1976). No other statistical treatment was used because of the short record and small sample size.

The indices were then analysed using the cluster analysis (MAT routine) from the International Tree-Ring Data Bank (ITRDB) program library. The purpose was to reveal how the samples were grouped: by species, by site features, a combination of the two, etc. However, according to the program there were too few series, and therefore the samples could not be clustered. Additionally, the ITRDB program library is now somewhat dated, and in discussion with operators of the ITRDB it was suggested that a statistical package could achieve the same results (Grissino-Mayer *pers. comm.* 2000). The cluster analysis procedure in SPSS was then used in an attempt to overcome this problem. Under SPSS, the samples did cluster; however, the results were inconsistent because the clustering was different for each of the tree-ring variables. Generally, one large cluster was evident, and the smaller clusters consisted of only one or two samples. As the results from the cluster analyses were unclear, the dendrograms from the 'best' dendrograms (where the samples clustered in several large groups) were analysed in terms of consensus groupings (Campbell & McAndrews 1991).

ii) Climate Data

Daily temperature and precipitation data were obtained from Environment Canada (1913 to 1991) and Fire Weather Index (FWI) from the Territorial Forest Fire Centre in Fort Smith (1955-1996). Average annual temperatures and precipitation were calculated. For the FWI data, the 10 maximum consecutive values for each fire season (May-September) were averaged for each of the FWI drought components (DC, DMC, and BUI). This is because "a season composed primarily of low and extreme days is considered worse than one composed of moderate days" (Simard 1990). The duff moisture code (DMC), because it measures the moisture content of loosely compacted organic layers 5-10 cm in depth, takes temperature, relative humidity and precipitation into account. The DC, or drought code, consists only of the temperature and precipitation since it measures the moisture content of deep compact organic layers at 10-20 cm. Because the moisture is measured at specific depths, the codes have a unique lag time of 12 and 52 days respectively. The BUI (build-up index) is a weighted combination of DC and DMC and gives an indication of the total amount of fuel available for burning (de Groot 1988, Hirsch 1996). The threshold values for

fuel type C-2 (boreal spruce) and C-3 (mature jack or lodgepole pine) in the Fort Smith area are 80 for the BUI, 20 for the DMC and 350 for the DC (Dave Hahn, *pers. comm.* 1999).

The FWI has only been measured since 1955, but because temperature and precipitation data have been recorded since 1913, the DC can be calculated from that time forward. Unfortunately the other codes could not be calculated because of incomplete and inconsistent records. To examine the relationship between the DC and the fire events based on fire scars, the DC was graphed from 1915 to 1995, and the fire years identified on the same graph (Fig. 10).

iii) Dendroclimatological Data

Once the daily FWI data were converted into annual values, each of the FWI series were correlated with the 29 tree-ring series using a number of different methods. The first method was to group the tree series by species, that is, pine and spruce. The four series of ring width, (earlywood width, relative earlywood width and maximum latewood density) for each of the species (eight series total) were then correlated to the DC, DMC, and BUI. The second method was to group the samples based on the consensus groupings that resulted from the cluster analysis produced by SPSS (Campbell & McAndrews 1991). With this method, the tree series fell into four groups based on degree of moisture. These series groupings were then correlated to the three drought components of the FWI. The correlations were then tested for significance at the 95% level (Lowry 2001).

RESULTS

a) Climate Data

Temperature and precipitation data had the longest records, from 1915 to present. To observe long-term trends, the average annual temperature was plotted, the results indicating a 1.4°C rise in temperature from 1915 to 1991 (Fig. 7). The total annual precipitation was also plotted for the same period, and as with the temperature, the long-term trend indicated a 100 mm rise over the same period (Fig. 8).

To examine the fire season, FWI data, specifically the averages of the highest ten consecutive values of each fire season for DC, DMC, and BUI. These data were plotted and compared with the threshold values for the fuel types in the area, C-2 (boreal spruce) and C-3 (mature jack or lodgepole pine) 350, 20, and 80 respectively. The plotted data showed that for the DMC, the threshold value (20) was exceeded every year, the DC only fell beneath the threshold value of 350 for two years between 1955 and 1995, and only 9 times did the BUI fall below the threshold of 80 for the same time period (Fig. 9).

The DC was the only drought component that could be calculated back for as long as the weather records were kept. Once the 10 highest consecutive values for each year were averaged and plotted on a graph, and the fire years, based on the fire scars, were identified on the same graph, it was evident that fires could occur any year (Fig. 10). Based on the DC data, there was no consistency in terms of when the fires occurred, as ignitions occurred in years with very low annual DC values as well as in years with high annual DC values.

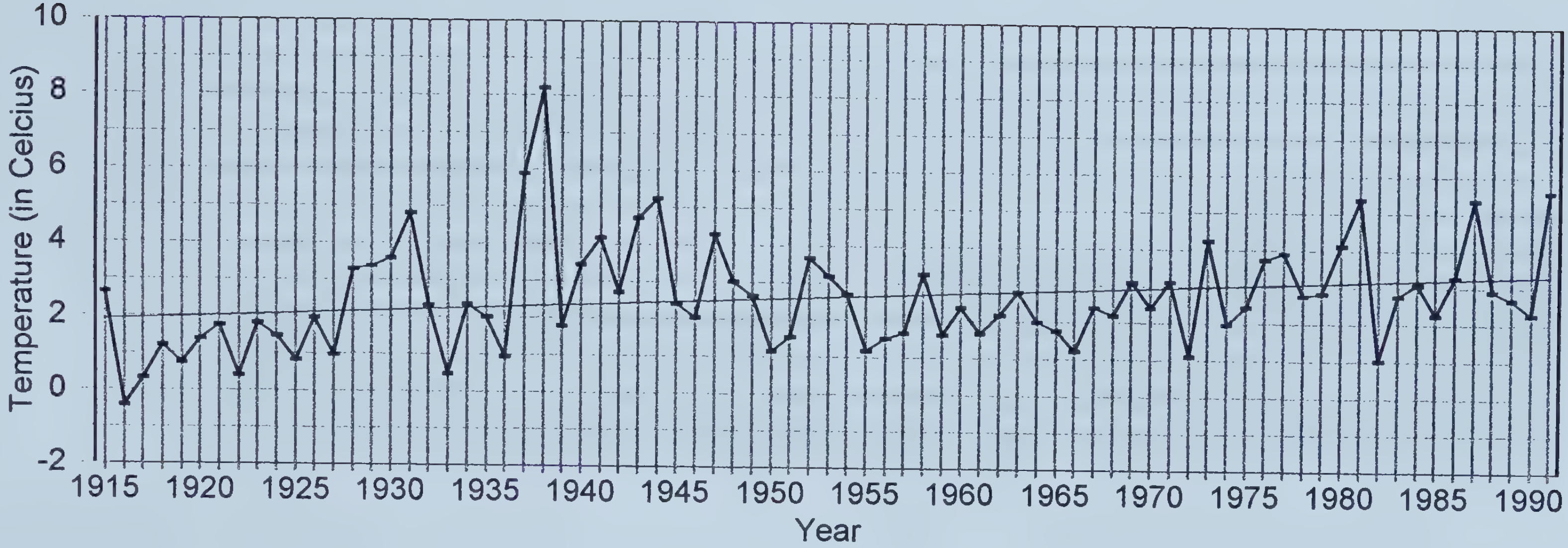


Figure 7. Average annual maximum daily temperature for Fort Smith, NT. The linear fit appears to suggest a warming trend over the 77 years (1915-1991) of 1.4°C.

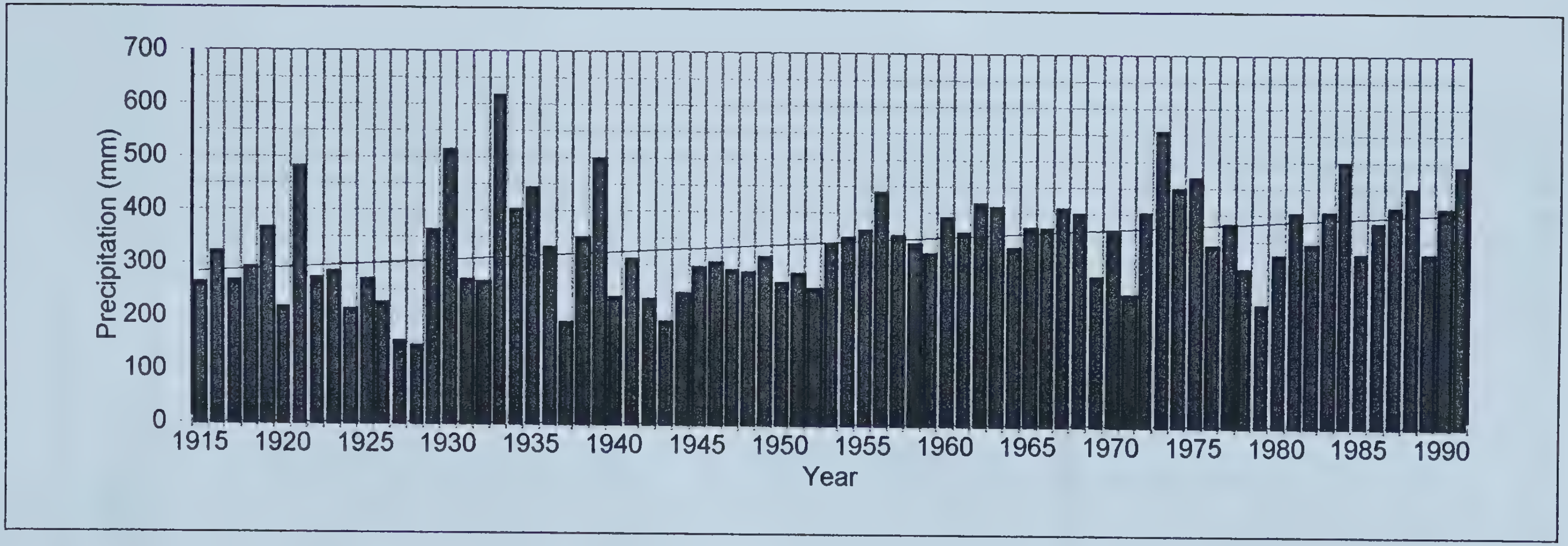


Figure 8. Total annual precipitation for Fort Smith, NT. The linear fir appears to suggest an increase in precipitation over the 77 years (1915-1991) of just over 100 mm.

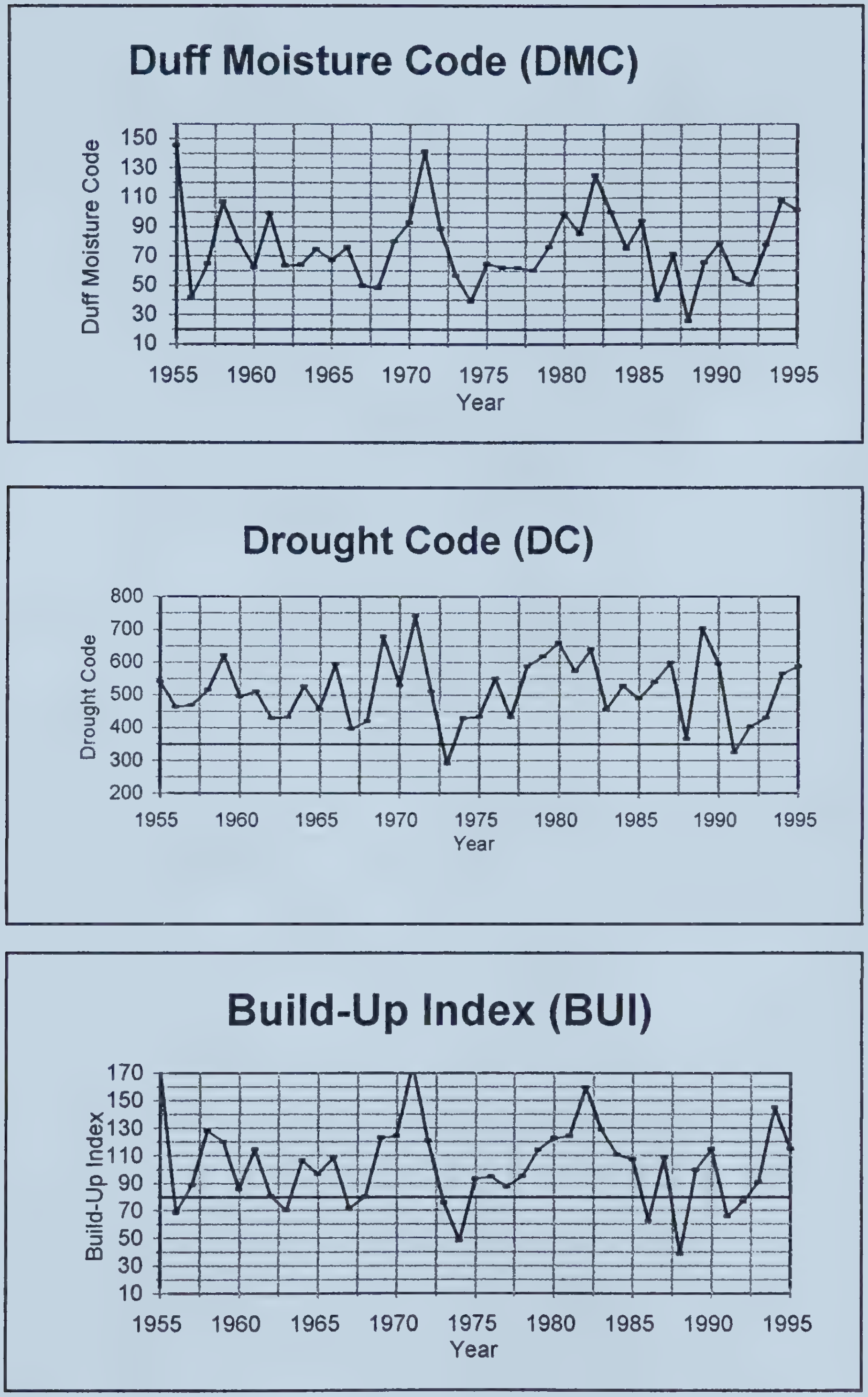


Figure 9. Average annual 10 day maximum for the DMC, DC, and BUI at Fort Smith, NT from 1955-1995. Shown with C-2 (boreal spruce) and C-3 (mature jack or lodgepole pine) fuel type threshold values.

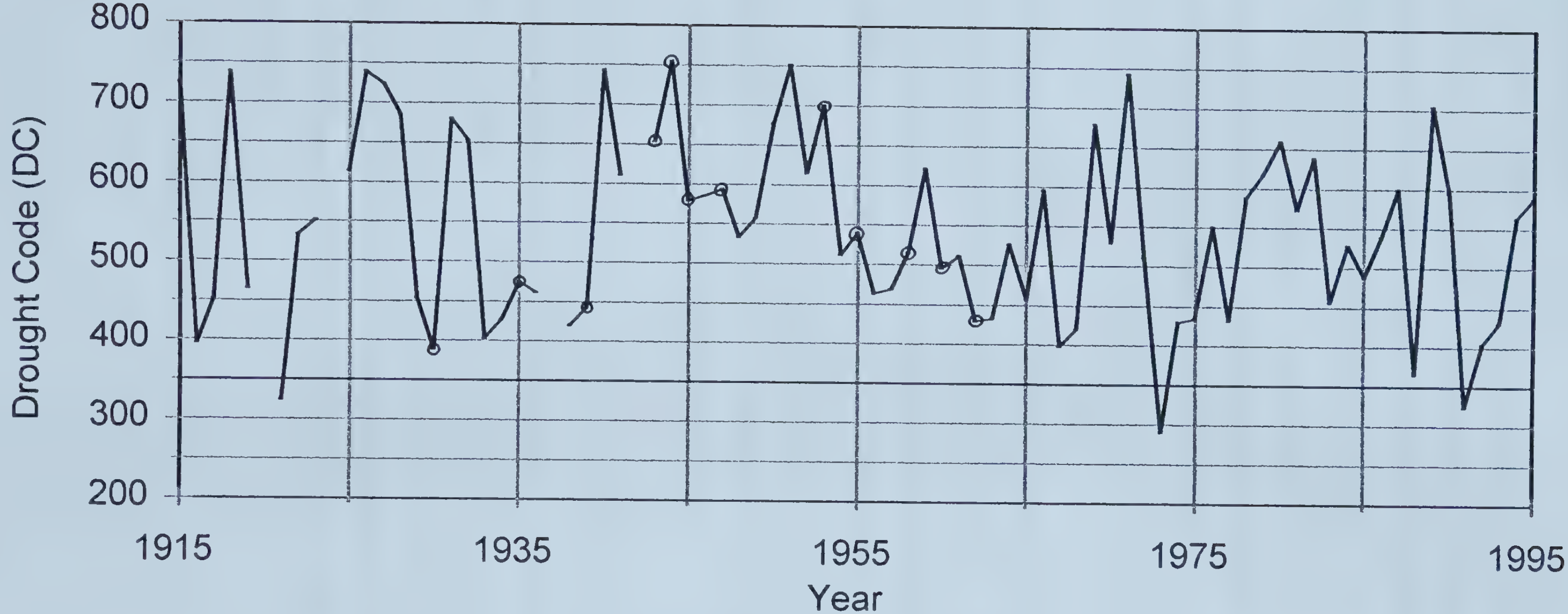


Figure 10. Average of the annual 10 highest consecutive values for DC for Fort Smith, NT from 1915-1995. Threshold for DC in C-2 and C-3 (boreal spruce and pine) fuel is 350. Circled points indicate fire events, based on fire scars.

b) Dendrochronological Data

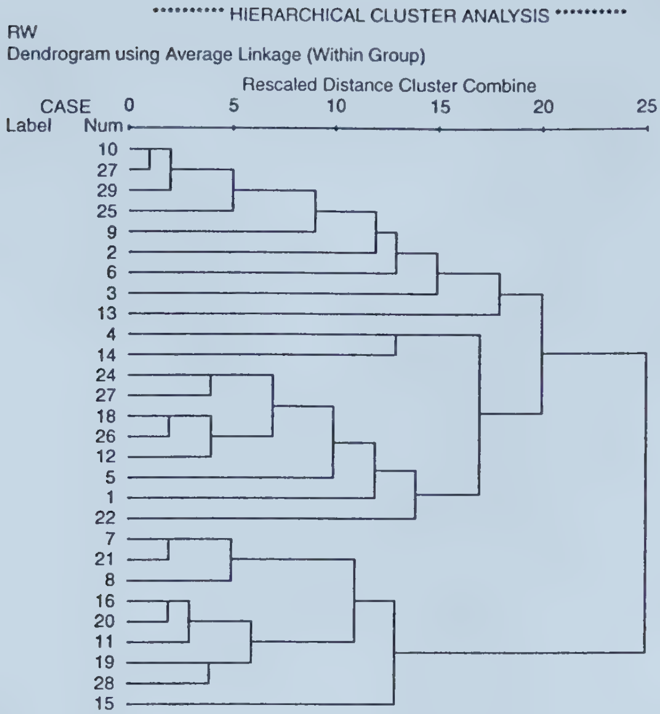
The linking of tree growth with fire weather was attempted by grouping the trees by species and correlating ring width, earlywood width, relative earlywood width and maximum latewood density of both pine and spruce trees with DC, DMC, and BUI. The results were extremely disappointing, as the correlations were very weak (Table 2). A time lag was also tested, where fire weather from one year was correlated with the following year's tree-ring growth. This analysis too exhibited weak correlations (Table 2). Only 2 of the 48 correlations showed significance, specifically, the DMC was negatively correlated with both ring width and earlywood width for pine trees for the current year's growth.

Because of the high degree of landscape heterogeneity, another method of grouping the trees was sought, and a cluster analysis by SPSS (1997) was performed. The results, regardless of method, were ambiguous, as there was no consistent grouping of the trees among tree-ring variables even within the same method (Fig. 11). The dendrograms that had the broadest or 'best' groupings were then put through consensus group analysis, and seven of the eight dendrograms agreed on four large groups which corresponded with differences in hydrology within the study area based on ground-truthed data (Fig. 12).

The four hydrological groupings were then correlated with the FWI drought components for the current year's growth, which resulted in correlations that were as weak as the species groupings (Table 3). However, 7 of the 48 correlations were significant: DMC was negatively correlated with ring width as well as earlywood width within the hydrological groupings of 'less dry' and 'wet'; the BUI was negatively correlated with ring width for the same groupings, but for earlywood width, the only significant correlation with BUI was for the wet hydrological group.

Pine					Spruce				
without lag	RW	EW	REW	MLD	without lag	RW	EW	REW	MLD
DC	-0.106	-0.102	-0.170	0.170	DC	-0.195	-0.183	-0.070	0.301
DMC	-0.419*	-0.392*	-0.084	0.068	DMC	-0.262	-0.242	-0.112	0.232
BUI	-0.342	-0.327	0.013	0.112	BUI	-0.250	-0.231	-0.060	0.252
with lag	RW	EW	REW	MLD	with lag	RW	EW	REW	MLD
DC	-0.312	-0.292	0.066	0.179	DC	-0.198	-0.170	0.021	0.254
DMC	-0.257	-0.241	-0.126	-0.100	DMC	-0.115	-0.093	0.091	0.188
BUI	-0.274	-0.274	-0.125	-0.035	BUI	-0.152	-0.130	0.069	0.201

Table 2. Correlation of three Fire Weather Index (FWI) components (drought code (DC), duff-moisture code (DMC) and build-up index (BUI)) with four tree-ring variables (ring width (RW), earlywood width (EW), realtive earlywood width (REW) and maximum latewood density (MLD) by species for the same fire season and growth year (without lag) as well as for this year's fire season and the following year's growth (with lag). * Indicates a significant correlation at the 95% confidence level.

a. 

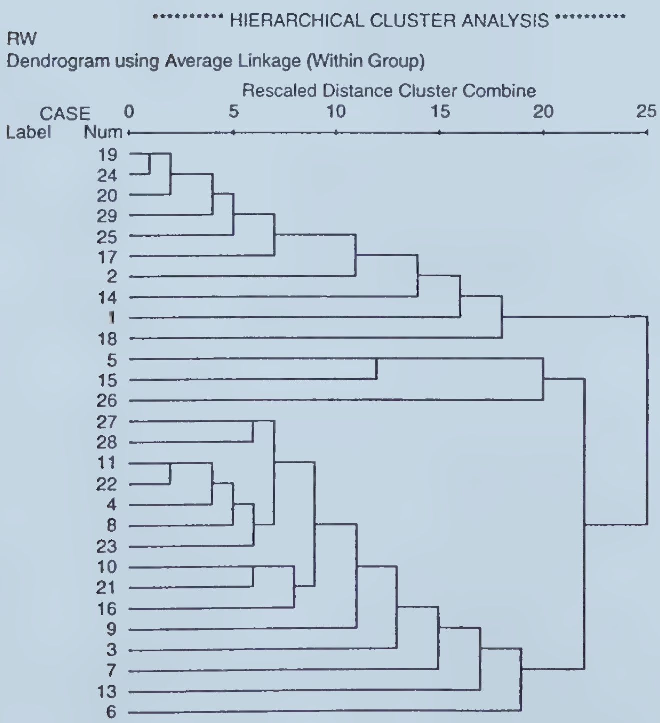
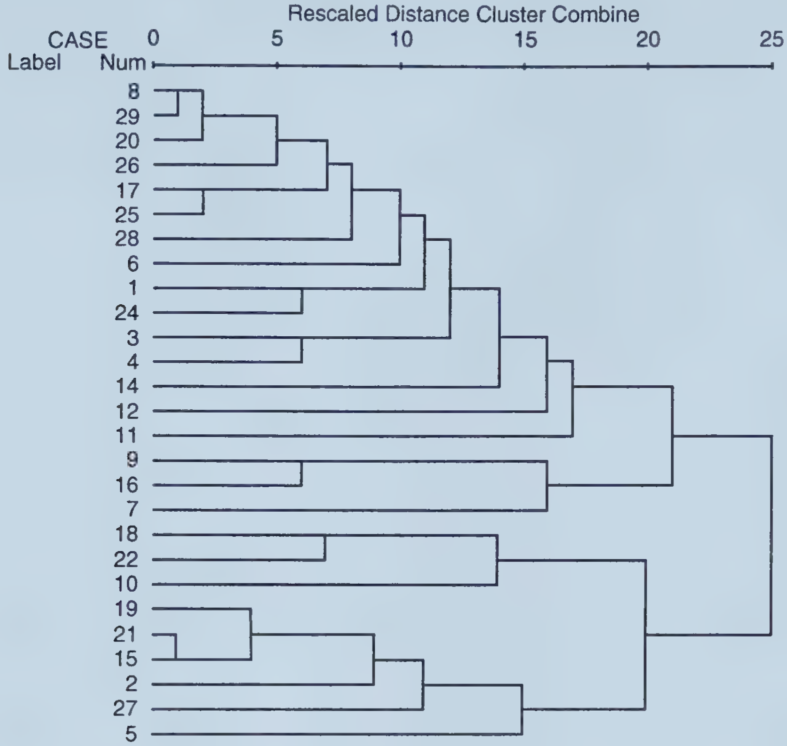
b. 

Figure 11, a-h. Cluster analysis of 29 trees around Fort Smith, NT, using SPSS, for the purpose of developing a master chronology. Four tree variables were examined (ring width, earlywood width, relative earlywood width, maximum latewood density) from two main groups, pine (*Pinus banksiana*) and spruce (*Picea glauca* and *P. mariana*).

********** HIERARCHICAL CLUSTER ANALYSIS **********

c. MId

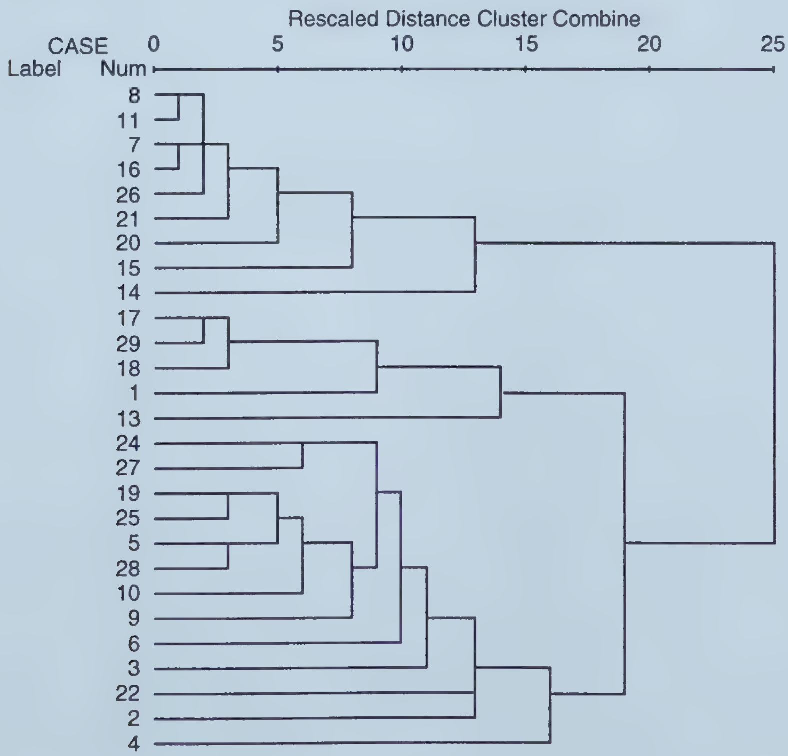
Dendrogram using Average Linkage (Within Group)



********** HIERARCHICAL CLUSTER ANALYSIS **********

d. EW

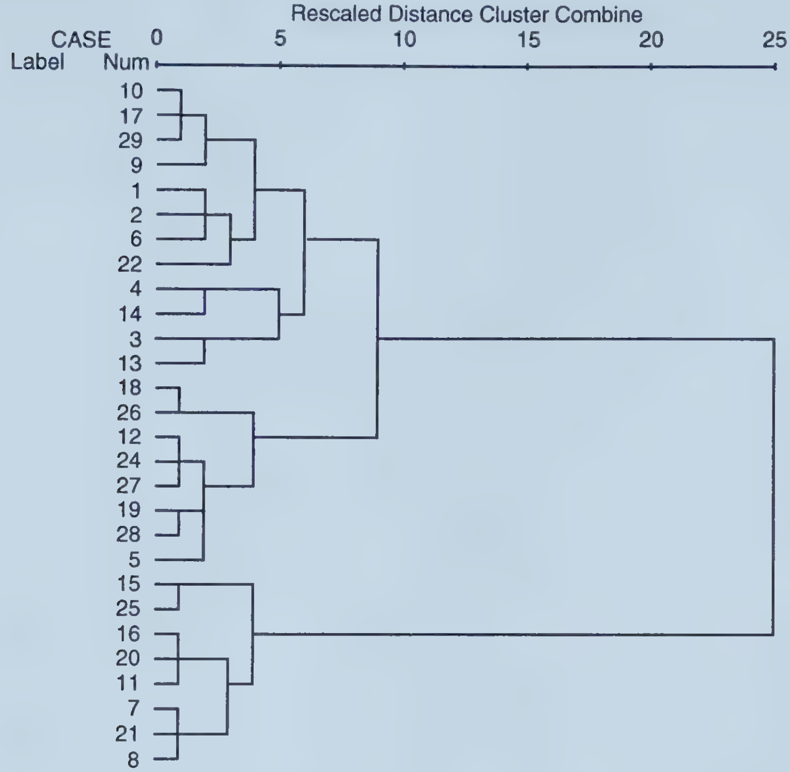
Dendrogram using Average Linkage (Within Group)



********** HIERARCHICAL CLUSTER ANALYSIS **********

e. RW

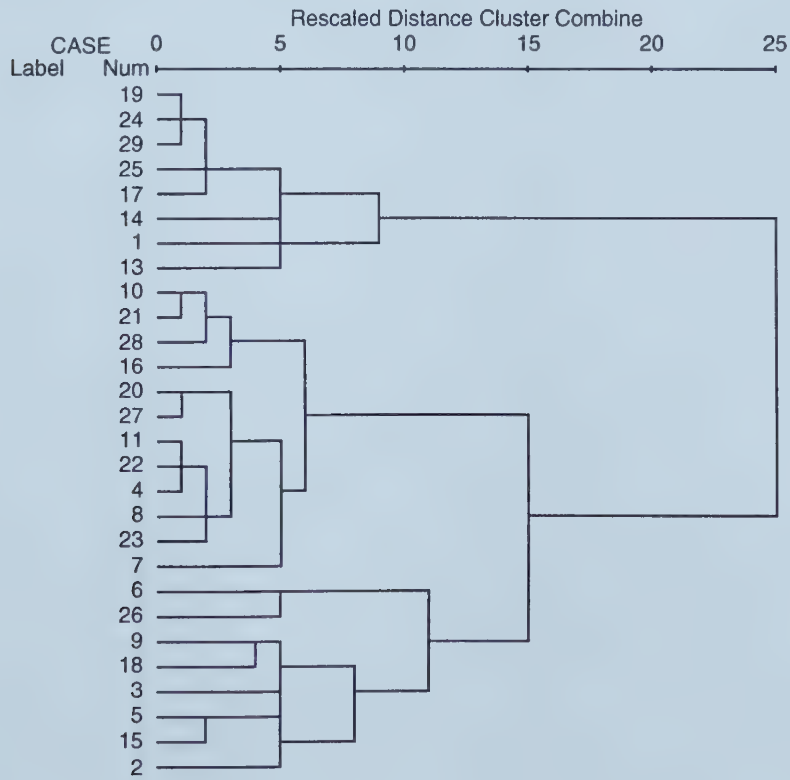
Dendrogram using Ward Method



********** HIERARCHICAL CLUSTER ANALYSIS **********

f. REW

Dendrogram using Ward Method

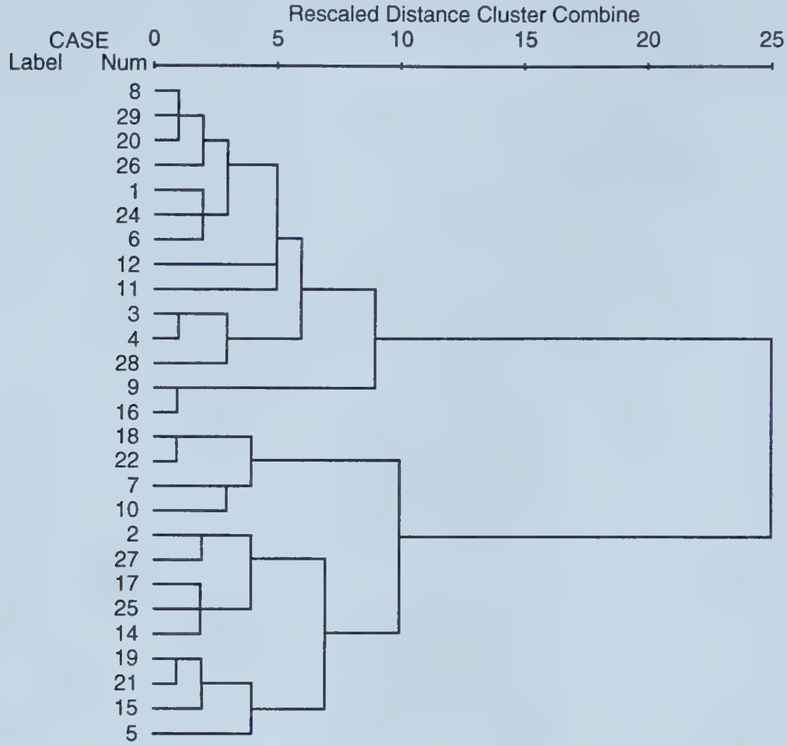


g.

********** HIERARCHICAL CLUSTER ANALYSIS **********

MLD

Dendrogram using Ward Method

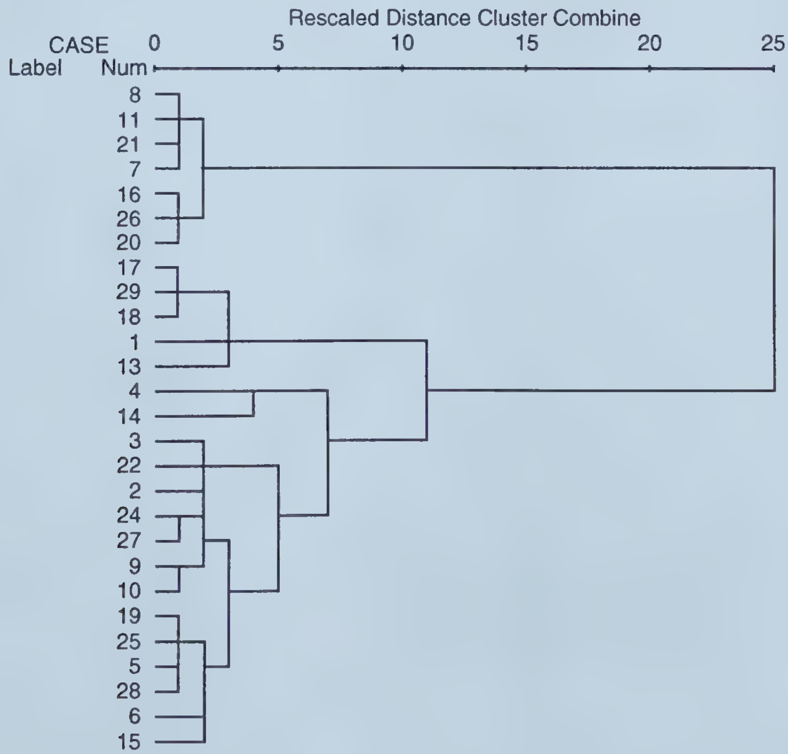


h.

********** HIERARCHICAL CLUSTER ANALYSIS **********

EW

Dendrogram using Ward Method



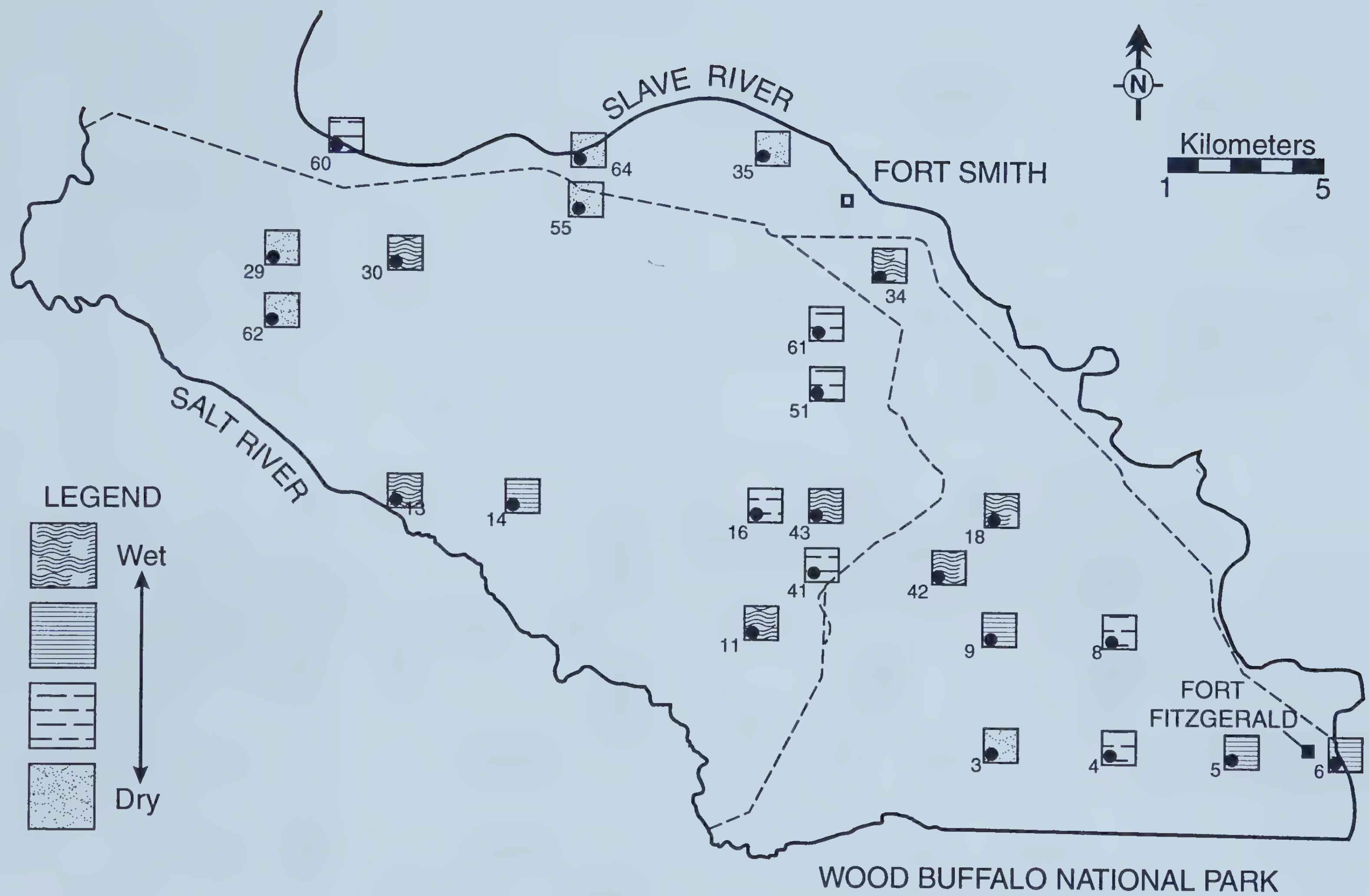


Figure 12. Grouping of sites of unscarred trees included in drought chronology based on consensus grouping (7 of 8 dendrograms agree on the four groups).

Ring Width				
	Dry	Less Dry	Wet	Very Wet
DC	-0.019	-0.211	-0.183	-0.135
DMC	-0.324	-0.498*	-0.440*	-0.079
BUI	-0.222	-0.456*	-0.367*	-0.097
Earlywood Width				
	Dry	Less Dry	Wet	Very Wet
DC	-0.029	-0.165	-0.180	-0.109
DMC	-0.328	-0.381*	-0.461*	-0.093
BUI	-0.239	-0.357	-0.385*	-0.127
Relative Earlywood Width				
	Dry	Less Dry	Wet	Very Wet
DC	-0.150	-0.058	0.061	-0.062
DMC	-0.042	-0.207	-0.259	-0.132
BUI	-0.004	-0.131	-0.176	-0.086
Maximum Latewood Density				
	Dry	Less Dry	Wet	Very Wet
DC	0.283	0.182	0.290	-0.121
DMC	0.180	0.010	0.275	-0.235
BUI	0.195	0.067	0.317	-0.253

Table 3. Correlation of three Fire Weather Index (FWI) components (drought code (DC), duff moisture code (DMC), and build-up index (BUI)) with tree-ring variables (ring width (RW), earlwood width (EW), relative earlywood width (REW), and maximum latewood density (MLD)) for hydrological groupings (Fig. 12) of sites with unscarred trees. * indicates a significant correlation at the 95% confidence level.

DISCUSSION AND CONCLUSIONS

a) Climate

The general upward trend of both temperature and precipitation is consistent with what many scientists have predicted using climate change models. Fires are expected to become larger and more frequent with climate change (Figs. 7, 8) (Flannigan & Van Wagner 1991, Gates 1990). "The major processes projected to be dramatically changed in the boreal forest are the frequency and intensity of disturbances such as insect and disease outbreaks, convective windstorms, and particularly fire" (Weber & Stocks 1998).

b) FWI

The study area falls into FWI zone 5 of 7, 7 being the most extreme in terms of fire weather, as the weather zones are based on average FWI (Simard 1990). With climate change, the increased temperature and the resulting increase in evapotranspiration, the periods of critical fire weather can be expected to lengthen and become more extreme.

c) Species

When the tree-ring series were grouped by species, only the series form pine trees were significantly correlated. In the study area, pine trees are found growing in large stands within a larger upland area (north of the 60^{th} parallel) and as small islands throughout the wetlands which dominated the study area. Perhaps it is these wetland jack pine that are responding to the changing moisture levels as there would be greater fluctuations of moisture on these islands than in the very xeric upland region.

d) Hydrology

Tree samples collected from 'less dry' and 'wet' sites were significantly correlated to fire weather likely because these sites would experience greater fluctuations in moisture than the 'dry' or 'very wet' sites, as the 'dry' sites were generally sand dunes and the 'very wet' sites were flooded.

e) FWI Moisture Components

The DC was not found to be significantly correlated with any of the tree-ring series unlike previous studies (Larsen & MacDonald 1995, Archambault & Bergeron 1992). The DMC, however, was significantly correlated to RW and EW for pine when the tree-series were grouped by species, and to sites that were 'wet' and 'less dry' when the tree series were grouped by hydrology (Tables 2, 3, Fig. 12). Perhaps this is because the depth at which the moisture is measured (5-10 cm) and the associated measurement of relative humidity, is more sensitive to drought than the DC, which takes only temperature and precipitation into account and measures moisture at a depth of 10-20 cm. Additionally, DMC only has a 12-day lag, compared to a 52-day lag for DC, so it is more responsive to fluctuations of moisture throughout the fire season.

The BUI was significantly correlated only because of the DMC, as the BUI is an index of the two moisture codes, DMC and DC.

f) Negative Correlations

Most of the series were negatively correlated. For the series that were significant, it means that as the DMC increases, there is less moisture and the tree's growth is inhibited, resulting in narrower rings. The same applies to the BUI.

g) Current Year's Growth

The tree-ring series were correlated to this year's growth likely because the high and fluctuating water table moderates the effects of the current year's drought on the following year's growth.

h) Tree Ring Series

Only ring width and earlywood width series were significantly correlated to critical fire weather. Because the average of the highest 10 consecutive values of each DMC, DC, and BUI was used to describe the moisture level of the entire fire season, the moisture data was reduced to a seasonal value, that perhaps was not specific enough to identify critical fire

weather early or late in the season. As ring width is an indicator of drought over the fire season, it is not surprising that it was significantly correlated to fire weather. Ring width is most influenced by earlywood width, particularly in the Fort Smith area where the growing season is very short, and therefore the earlywood growth would represent the majority of the fire season.

i) Evaluation of Data

Because of climate change, being able to reconstruct and identify the periods of critical fire weather by correlating FWI data with tree-ring series could have been extremely useful, but the correlations within this study area were particularly weak (Tables 2, 3). Luckman (1997) writes "a weak relationship between climate and tree growth is ambiguous. This result may be caused by a poor relationship between tree-growth and climate at the site, due perhaps to some local non-climatic effects (Type I effect) or because two sites experience differences in climate (Type II effect). In reality, there is probably a mixture of both Type I and Type II effects". It would appear that there is indeed a combination of both Type I and II effects acting on the tree-growth climate relationship in the Fort Smith study area. Some of the effects include the meteorological records, the landscape, and the trees that were sampled (Archambault & Bergeron 1992, D'Arrigo *et al.* 1992, Fritts & Schatz 1975, Johnson & Van Wagner 1985, LaMarche 1974, LaMarche & Stockton 1974, Weber & Stocks 1998).

"[R]egions with short or poorly documented human histories must rely primarily on the evidence from natural archives", but to use tree rings for proxy climate data requires long instrumental records (Luckman 1997). This is, unfortunately, not possible in many parts of Canada where records inconsistently go back only to 1913, and in the Territories only to 1946 (Weber & Stocks 1998). Even where there are records that extend back for a long period of time, the reliability of the data is questionable. The records in the Fort Smith area date from 1913, the data pre-1955 being extremely unreliable, with many periods of missing data as well as inconsistencies between stations. The FWI data, however, while not inconsistent, only cover a very short period, back to 1955.

The landscape of the study area is extremely heterogeneous, which could mean that the trees were responding to the differences in microclimates, and therefore could not be correlated (LaMarche 1974). "Each tree is an individual...individuals can react differently" (Tessier *et al*. 1997). Additionally, the study area falls into the region of discontinuous permafrost, which may also add to the difficulty in correlating different samples from different sites, as some trees would be growing under permafrost conditions and others would not be (Weber & Stocks 1998). The wetlands may have also had an effect on the tree-ring growth, particularly as there is yearly variation in the water table, perhaps confounding the climatic effects (Dang & Lieffers 1988, Mannerkoski 1985). In comparing this study with that of Archambault and Bergeron's (1991), the sites in their study were quite homogenous.

The trees used in the Fort Smith area presented a number of difficulties. While Archambault and Bergeron (1992) had a series that was 802 years in length, the series for the Fort Smith area was only 225 years. The short length of the series in the Fort Smith area was due to at least two factors, the tree species and the large stand-replacing fire of 1953. Both jack pine and black spruce species are relatively short-lived, the oldest tree in the study dating from 1770 (Desponts & Payette 1993). The large stand-replacing fire of 1953 was the likely cause of the fact that more than half of the samples were only 30 to 40 years in age (thus originating after the 1953 fire which burned more than one-third of the study area). Generally, results from areas which have more than one-third of the study area burned are unreliable (Johnson & Gutsell 1994).

The number of replications in this study was low compared with Archambault and Bergeron's (1991), as the author was limited in the number of trees that could be sampled and the number of discs that could be carried out by the research team by the end of the day. Also, many of the unscarred samples exhibited numerous perturbations within the ring series and therefore were excluded from the chronology. Another potential difficulty in terms of the correlation was the individual ring variation. "The best dendrochronological material often comes from extreme environments, such as semi-arid sites...where tree growth is clearly limited by climatic factors (LaMarche & Stockton 1974). Fritts and Shatz (1975)

agree, "the more climate is limiting to the trees of a given region, the better the correlation among chronologies." Conditions within the Fort Smith area were not limiting, again, due in part to the hydrology of the area combined with the heterogeneity of the landscape, with the result that the variation between individual rings was quite low (Campbell & Varem-Sanders *pers. comm.* 1997).

j) Conclusion

It was hypothesised that the FWI moisture codes (DC, DMC, and BUI) from 1955 to 1995 could be correlated to tree ring series from 1770 to 1995. The hypothesis was correct for ring-width and earlywood width series from pine trees as these were significantly negatively correlated with the DMC (duff-moisture code) of the current year. It was also correct for Ring-width series of trees that were found on sites that were 'wet' and 'less dry', as these too were significantly negatively correlated to both the DMC and BUI as were the earlywood width series from the 'wet' sites. The earlywood series from the 'less dry' sites were only significantly negatively correlated to the DMC. Now that a relationship has been established between tree-growth and fire weather for the Fort Smith region, future research can reconstruct the drought history of the area and examine that history for patterns. There were, however, a number of difficulties presented not only by the study area, but also the tree-ring and meteorological data. Therefore, perhaps it is best to consider the approach used in this study, namely linking tree-growth and fire weather in the Fort Smith area, to be preliminary. Future studies might increase the sampling intensity, expand the size of the study area, find more trees with longer records, use a different definition of drought, analyse the data using multiple regression, or investigate the effects of microtopography and/or hydrology on tree ring growth.

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CHAPTER 3
FUEL CORRIDORS AND BREAKS AROUND THE FORT SMITH SETTLEMENT

INTRODUCTION

Forest and fuel "management becomes increasingly critical in forest ecosystems located adjacent to residential areas" (Kalabokidis & Omi 1998). But to manage a forest and fuels within it, there must be an understanding of the vegetation within the forest ecosystems (British Columbia Ministry of Forests 1994, Foster 1983, Hirsch 1992). The vegetation of the area surrounding Fort Smith, Northwest Territories is not well understood for a number of reasons, including difficult access (the study area is dominated by wetlands). The only digital maps of the region are at 1:250 000 scale, which does not provide enough detail in terms of fuel breaks and corridors.

Although the area is dominated by wetlands, it is during years of extreme fire weather that large stand-replacing fires could occur and threaten the community of Fort Smith as well as other values-at-risk within Wood Buffalo National Park. While there are ignition sources near the town, the Park also presents a source of fire danger to the community, as every year fires burn within the Park.

Air photo analysis is commonly used to analyse vegetation on a large scale, particularly in remote areas (Nesby 1997, Vitt *et al*. 1997). The Fort Smith study area is ideal for air photo analysis as it is remote and difficult to access. However, air photo analysis must be accompanied by ground-truthed data in order to ensure the accuracy of the interpretation of the vegetation.

In Alberta, vegetation is most commonly inventoried by using the Alberta Vegetation Inventory (AVI) (Nesby 1997). However, as the AVI "was designed and developed specifically to meet the information needs of forest managers" it tends to focus "on the location, extent and condition of forest resources" in terms of forest products. Because most of the area around Fort Smith is dominated by wetlands, analysis of the vegetation in terms

of harvestable timber is not particularly useful in terms of understanding the vegetation and potential fire danger. Vitt *et al.* (1997), however, developed an alternative vegetation inventory method, the Alberta Wetland Inventory (AWI).

The AWI appears to be more suitable for analysing the vegetation in the study area: the region is dominated by wetlands, and the AWI presents a larger picture of the type and amount of vegetation and the hydrology (rather than just identifying vegetation in terms of harvestabilty as is the case with the AVI methodology). Each wetland polygon receives a wetland code that incorporates those aspects into the interpretation. It is therefore hypothesised that the AWI method accurately identifies vegetation within the Fort Smith area and can therefore be used to identify and locate natural fuel breaks and corridors.

The objective of this study was to gain an understanding of the vegetation in the area surrounding the town of Fort Smith, NT, in order to identify natural fuel corridors and breaks. This is the first step in establishing fire management policies to manage fuels within the corridors and establish various lines of defence in the breaks.

Methods

a) Field

Random and stratified sampling approaches were used for the ecological assessment. Using a four-kilometre grid, completely random points were identified on topographic maps at 1:50 000 and then located in the field using the helicopter GPS. Stratified sampling was determined by interpretations of broad scale units of vegetation types from 1987 air photos. Because a higher sampling intensity was required in coniferous areas in order to sample more trees for the drought and fire chronologies, a two-kilometre grid was used in this vegetation type. Each site was inventoried using the relevé method to establish the percent cover of each species of plant encountered.

b) Laboratory

To map the vegetation of the study area, the four 1:50 000 topographic maps were digitised using GRASS shareware in order to create a base map. The base map was then enlarged to 1:20 000 to match the scale of the air photos, and printed on Mylar. The air photos, which were flown in August-September of 1996, were interpreted using the AWI classification scheme, because the area is primarily wetland. Non-wetland areas (uplands) were identified to dominant tree species only.

Polygons from the uncorrected air photos were transferred onto the Mylar sheets and then digitised, using GRASS, and edited and labelled with ARCINFO. Although thousands of polygons were identified, lines in between polygons of the same vegetation type were removed for the production of the map even though there may have been differences between polygons of the same vegetation type.

i) Comparison of Air photo and Ground-Truthed Classifications

A table was created in order to carry out the comparison between the ground-truthed data and the interpretation of the air photos (Table 4). From the ground-truthed site data, two dominant species were identified for each plant category (tree, shrub, other). Based on these species and their percent cover, the site was classified using the AWI criteria. These sites were then located on the map that was derived from the AWI classification of air photos, and the vegetation type for the sites recorded. The ground-truthed and the air photo classifications were then compared to see the degree of matching between the two methods and if the AWI accurately represents the actual vegetation.

RESULTS

The AWI classified vegetation map of the Fort Smith area is presented as Map 1 at a scale of 1: 50 000. The area is clearly dominated by treed fens, but there are some important exceptions. The northern boundary of the study area is dominated by *Pinus banksiana*, but generally only as far south as the 60th parallel. Along the Salt River, the dominant vegetation is *Populus tremuloides*, which extends to some degree to the southern boundary.

Picea glauca dominates the area immediately along the Slave River, however, the southern and lower parts of the eastern boundaries are rather heterogenous. The area southwest of the settlement is dominated by open fens, which can also be found scattered throughout the study area, and the central to eastern parts are marked by paleochannels and various types of vegetation.

The ground-truthed data are available for 62 sites within the study area, and therefore serve as a spot check in comparing the ground-truthed data with the AWI method of air photo interpretation. Comparing the ground-truthed data with the air photo data resulted in 69.4% (43) of the sites matching (Table 4).

Discussion and Conclusions

The map produced from the air photos illustrates the heterogeneity in the landscape surrounding the town (Map 1). Although the study area is clearly dominated by wetland, its heterogeneous appearance is atypical for wetlands within the boreal forest (Beilman *pers. comm.* 1997, Halsey *pers. comm.* 1997). This high degree of heterogeneity is caused by a number of factors including edge effects from deglaciation and Glacial Lake McConnell (Fig. 13), (Sjogren *pers. comm.* 1998). In the boreal forest, fires tend to be large and of high intensity which results in large homogenous areas, particularly in *P. banksiana* forests where the fire regime is dominated by large crown fires (Van Wagner 1983). However, "lake landscapes are one of the few places where one can find a very complex arrangement of fire breaks in the boreal forest" (Bergeron 1991). Although this study area may not be a typical lake landscape, the numerous small lakes in combination with the large number and variety of wetland areas appear to have the same effect as a typical lake landscape and have created a complex arrangement of natural fuel breaks and corridors. It is therefore apparent that wetlands, like lakes, act as a barrier for both the spread of fire and anthropogenic influences.

	Airphoto	Water		Ground Truthed Site Features					AWI	
Site	Classification	(in cm)	Tree 1	Tree 2	Shrub 1	Shrub 2	Other1	Other 2	ground	Match
1	poplar/FTNN	7-20	sb 1%	tam <1%	salix 40%	betula 5%	carex 95%	petasag 12%	FONS	x
2	FTNN	1-3	at 10%		salix 30%		carex 100%	petasag 35%	FTNN	
3	FTNN	5-10	at 15%		salix 80%	betula 20%	carex 70%	juncus 30%	FTNN	
4	poplar		at 12%	jp 10%	shepcan 30%	arctuva 20%	grass 85%	linnbor 45%	poplar	
5	mixed wood		sb 60%	at 5%	shepcan 40%	salix 30%	equisyl 5%		mw	
6	poplar		bp 60%	ra 40%	vibedu 70%	rosaaci 15%	equisyl 40%		poplar	
7	poplar		at 30%	sw 30%	vibedu 30%	rosaaci 20%	linnbor 10%		poplar	
8	FTPN/FTNN		sb 30%		salix 60%	shepcan 20%	betula 10%	equisyl 50%	FTNN	
9	FTNN/MONG		at 50%	sw 30%	shepcan 40%	betula 35%	salix 30%	linnbor 40%	FTNN	
10	FONS	1-3	tam 7%		salix 60%	betula 10%	carex 85%		FONS	
11	FTNN		sb 2%		betula 20%	salix 15%	juncus 95%		FONS	x
12	FTNN	0-1	at 7%	sw 3%	betula 60%	salix 30%	juncas 50%		FTNN	
13	poplar		at 60%	bp 15%	rosaaci 38%		epilang 50%	corncan 35%	poplar	
14	FTNN	7	sb 1%	tam 1%	betula 60%	salix 30%	petasag 7%		FONS	x
15	mixed wood		tam <1%		betula 30%	salix 15%	carex 95%		FONS	x
16	FONS	1-30	tam 10%	sb 1%	betula 40%	salix 30%	carex 60%		FONS	
17	FTNN		sb 25%	tam 7%	salix 20%	ledugro 15%	equisci 45%		FTNN	
18	FTNN		sb 40%	jp 25%	ledugro 35%	vaccvit 30%	equisci 30%	linnbor 30%	FTNN	
19	FTNN		sb 55%	jp 10%	arctuva 25%	vaccvit 25%	pleusch 40%		FTNN	
20	FTNN		jp 30%	at 10%	arctauva 35%	shepcan 10%	corcan 15%	cladina 40%	jp	x
21	white spruce		jp 30%	sw 4%	vaccvit 30%	rosaaci 12%			jp	x
22	jp/FTNN		jp 30%	sw 6%	arctuva 40%	vaccvit 30%	lichens 65%		jp	
23	FTNN	0-40	sb 30%	tam 10%	arctrub 10%	salix 5%	equisci 15%	carex 20%	FTNN	
24	FTNN	1-2	sb 20%	tam 2%	betula 40%	salix 35%	juncas 85%	pleusch 65%	FTNN	
25	poplar/FONS	10-40	sb 25%		betula 60%	salix 40%			FTNN	x
26	FTNN	1-2	sb 60%	at 15%	betula 40%	salix 40%	pleusch 100%	calacan 90%	FTNN	
27	poplar		at 70%		betula 35%	salix 25%	epilang 25%		poplar	
28	MONG	0-10	sb 30%	tam 2%	vaccvit 60%	ledugro 30%	carex 90%		FTNN	x
29	FTNN		sb 60%		salix 10%		hylospl 35%		FTNN	
30	FTNN		sb 30%	jp 20%	salix 15%	vaccvit 15%	linnbor 23%	lichens 55%	FTNN	x
31	FTNN	1-2	sb 25%	tam 5%	betula 35%	salix 25%	equisci 40%	equisyl 30%	FTNN	

32	FTNN/FONS	1-2	sb 35%	tam 3%	betula 35%	arctrub 15%	equiarv 60%	hylospl 15%	FTNN	
33	FONS		jp 10%		arctuva 40%	vibuedu 20%	cladina 60%	peltigeria 30%	jp	x
34	FTNN	0-5	tam 15%	sb 10%	betula 25%	salix 12%	equisci 45%	carex 15%	FTNN	
35	jack pine		jp 30%		arctuva 75%	salix 10%	equiarv 15%	hylospl 30%	jp	
36	mixed wood		sw 30%	jp 20%	aw 10%	shepcan 10%	corncan 15%	pleusch 40%	mw	
37	shrub		sb 60%				corncan 20%		sb	x
38	poplar		at 30%	sw 10%	shepcan 60%	vaccvit 12%	geocliv 6%		poplar	
39	white spruce		sw 35%	jp 20%	vaccvit 50%		elyminn 70%	pleusch 95%	sw	
40	jack pine		jp 50%		arctuva 50%	maiacan 10%	hylospl 85%	cladina 60%	jp	
41	FTNN		sb 30%	jp 20%	arctuva 45%	vaccvit 25%	linnbor 30%	cladina 80%	mix	x
42	FTNN/jp		jp 50%	sw 20%	vaccvit 25%	shepcan 15%	corncan 20%	hylospl 30%	jp	
43	FTNN		sw 40%	tam 2%	salix 15%	betula 5%	equiarv 55%	pleusch 100%	FTNN	
44	FTNN/mw/sb		jp 40%		arctuva 50%	shepcan 15%	geocliv 20%	clad 65%	jp	x
45	mixed wood	0-20	sb 80%	tam 1%	salix 70%	arctrub 40%	pleusch 70%		FTNN	x
46	jp/sw		jp 30%	sw 5%	arctuva 75%	rosaci 45%	maiacan 30%	peltiger 60%	jp	
47	FTNN		sb 40%	tam 10%	betula 27%	ledugro 25%	pyroasa 15%	hylospl 30%	FTNN	
48	white spruce	0-10	tam 15%	sb 10%	salix 30%	arctuva 20%	equiarv 50%	pleusch 60%	FTNN	
49	FTNN	0-15	sb 80%	tam 10%	arctuva 20%	salix 15%	equiarv 60%	pleusch 50	FTNN	
50	jack pine		jp 50%	at 30%	alnucri 60%	shepcan 15%	maiacan 40%	pleusch 100%	jp	
51	FTNN/FONG		jp 60%	sw 10%	vaccvit 30%	linnbor 25%	corncan 20%	clad 20%	jp	x
52	FTNN/shrub		sb 40%		salix 35%	betula 25%	pleusch 40%		FTNN	
53	FTNN/jp		sb 85%	tam 1%	salix 30%	arctrub 30%	hylospl 70%		FTNN	
54	mixed wood		bp 75%	sw 30%	rivalder 6%	rosaaci 20%	equisyl 45%		mw	
55	FTNN		sw 18%	at 15%	jp 10%	vibedu 45%	lathoch 30%	hylospl 60%	mw	x
56	sw/poplar		sb 65%		salix 10%	equisci 40%	geocliv 10%	hylospl 55%	FTNN	x
57	poplar/mw		at 60%	sb 3%	betula 25%	rosaaci 20%	elyminn 40%		poplar	
58	poplar		jp 60%	at 7%	arctuva 50%	shepcan 15%	calacan 25%	hylospl 30%	jp	x
59	FTNN		tam 40%	jp 1%	betula 85%	salix 30%	calacan 70%		FTNN	
60	white spruce		sw 65%	at 2%	vibuedu 30%	rosaaci10%	hylospl 30%		sw	
61	FTNN	0-10	tam 22%	sb 15%	salix 30%	equiarv 60%	pluech 60%		FTNN	
62	FONS		sw 10%	sb 10%	tam 5%	salix 40%	betula 40%		FTNN	x
	*jp=jack pine; mw=mixed wood; sb=black spruce; sw=white spruce									

Table 4. A comparison of ground-truthed data and AWI interpreted vegetaion for the Fort Smith, NT sample points

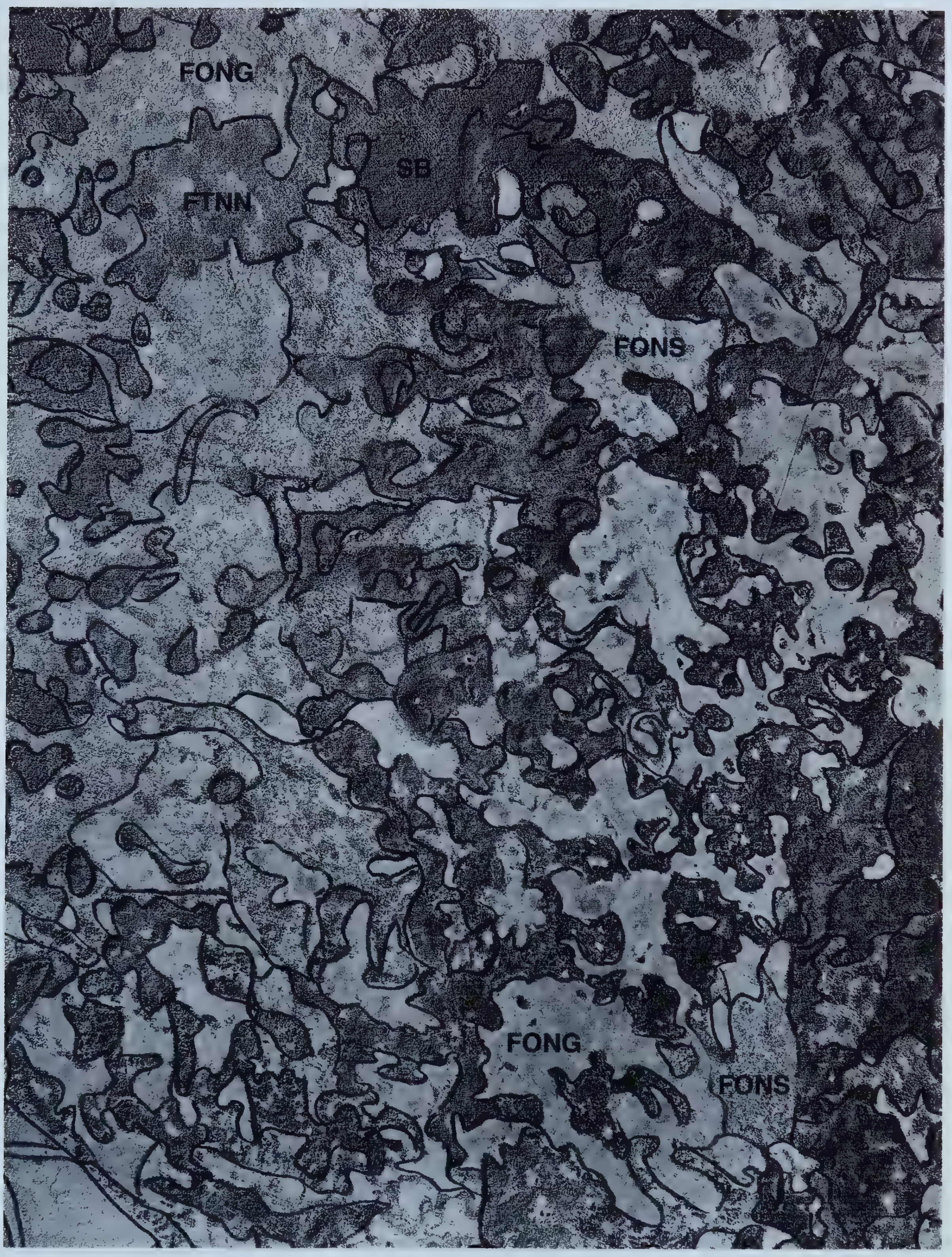

Figure 13. Air photo of Fort Smith NT study area (1 : 20,000), flown August-September, 1996 illustrating the high degree of landscape heterogeneity. Acronyms are as follows: FONG = fen, open, without patterning, graminoid dominated; FONS = fen, open, without patterning, shrub dominated; FTNN = fen, treed, without patterning, without permafrost; SB = black spruce.

Even though the landscape is complex, there are some well-known aspects of fire behaviour that can still be applied to the study area. The two dominant species types are spruce and pine, which exhibit different fire regimes. "Pine woodlands are more susceptible to fire than other fuel types [while] spruce woodland stands have very low fire frequencies [as] a thick mat of mosses...helps to retard fuel drying and may also decrease fire susceptibility" (Bergeron 1991). A fuel corridor exists along the eastern and northern boundaries of the study area and fires could follow this corridor northward from WBNP towards the town. Additionally, concern about fires moving eastward from the waste disposal area towards the town is legitimate due to the jack pine dominated vegetation between the dump and the town.

The Salt River and the surrounding vegetation will function as the most effective fuel break for fires moving north-eastward from the Park towards Fort Smith. The vegetation type is dominated by *Populus*, which is not very flammable; fire scar evidence indicates that there have been very few fires in that area over the past 225 years.

As for fires entering from the southern boundary of the study area, there are many paleochannels with numerous small bodies of water interspersed throughout the vegetation in the region east of the road and north to Four-Mile Lake, the large body of water south of Fort Smith. The south-central section of the study area has the most open fens, including many graminoid fens (Map 1). This area was burned by the 1953 fire (Delisle and Hall 1987) which would have reduced evapotranspiration and increased permafrost melting (Eastwood *et al.* 1998). Because of the slow recovery after disturbance in the boreal forest because "biomass production is low and decomposition is slow, this area would serve as a natural fire break (Schimmel & Granström 1997).

The AWI method was appropriate for the study area since the area is dominated by wetlands and it is the only method available for classifying wetland vegetation for the north-central boreal region. Table 4 shows a 69.4% (43 of 62 sites match) agreement between ground-truthed site data and the classification of vegetation from air photos. Although the

percentage of agreement is quite high, 19 sites do not show agreement between the air photo interpreted site and the ground-truthed data. This discrepancy can perhaps be explained by a number of factors including the high degree of landscape heterogeneity, locating the sites by GPS, use of uncorrected air photos, and the size of the polygons interpreted on the air photos. Because the map was being reduced from 1:20 000 to 1:50 000 in scale, polygons smaller than 1-2 cm could not be interpreted. Typical polygons in the area were exceptionally small, but because of the limitations of the mapping process small polygons had to be incorporated into larger ones which may not have been representative of the actual site, and therefore of the ground-truthed data. The lack of agreement could have also been caused by inaccurate site location, which has two components (location by helicopter and location of the sites on uncorrected air photos). The GPS of the helicopter was used to identify sites from the air, and confirmed by features of the topographic maps of the area. However, because of challenges related to helicopter transport, in some cases there were real difficulties in being able to get close to the sample site and this could have been exacerbated by the use of uncorrected air photos. Uncorrected air photos are most accurate towards the centre of the image and lose accuracy as one moves towards the edges. Compensations can usually be made by using landmarks on the base map; however, the Fort Smith study area lacks many landmarks, with the exception of a few lakes, the roads, and a handful of cultural features. Needless to say, the most difficult areas to map were also the areas that were wetland-dominated and had little or no anthropogenic features.

The hypothesis that the AWI method accurately identifies the vegetation within the Fort Smith area and can be used to identify natural fuel breaks and corridors is supported. However, because the landscape is so heterogeneous, the fuel corridors and in particular, the breaks, are extremely complex (Fig. 13). The fuel corridors appear to be somewhat more obvious and perhaps some fuel management policies could be developed for those vegetation types that are close to the Town and that lead from the Park towards the Town. As for natural fuel breaks, they are not so obvious and therefore instead of establishing permanent lines of defence, perhaps a number of scenarios need to be modelled and potential lines of defence identified for each of the scenarios, rather than establishing

permanent lines of defence.

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General Conclusions and Recommendations

Conclusions

1) Based on estimated-time-since-last-fire data, four fire regimes were identified for the Fort Smith region. The earliest period, from 1865-1895, had a fire cycle of 181 years and a frequency of 0.55%, while the period from 1895-1935 had the longest fire cycle of 266 years and a frequency of 0.38%. The period between 1935-1945 had the highest fire frequency, 3.40% and shortest cycle, 29 years. Since 1945, the shortest fire cycle has lengthened to 130 years and frequency has decreased to 0.77%. The fire interval is 40 years between establishment and the first fire, and 37 years between consecutive fires. These results are consistent with data from WBNP and imply that the Park and the Fort Smith area are similar landscape types.

2) A relationship between critical fire weather and tree-growth was established. Ring width and earlywood width series were found to be significantly negatively correlated with the DMC of the current growth year for jack pine trees and for trees sampled within ‘wet’ and ‘less dry’ sites. The BUI was also significantly correlated to ring width for trees in ‘less dry’ and ‘wet’ sites to earlywood width only for trees in ‘wet’ sites.

3) The area surrounding the town of Fort Smith, NT has a complex arrangement of fuel breaks. The fuel corridors, along the northern and eastern boundaries of the study area, are more easily identified. The AWI was successful in identifying both the jack pine corridor as well as the wetland complex which serve as fuel breaks.

4) Fort Smith, NT is surrounded by a variety of fuel types that range from low (wetlands) to high (jack pine) flammability. The jack pine corridor has been identified as the hazardous fuel in most years. In years with greater drought, the other upland fuel types will carry fires, and during periods of severe drought the wetland areas could also ignite.

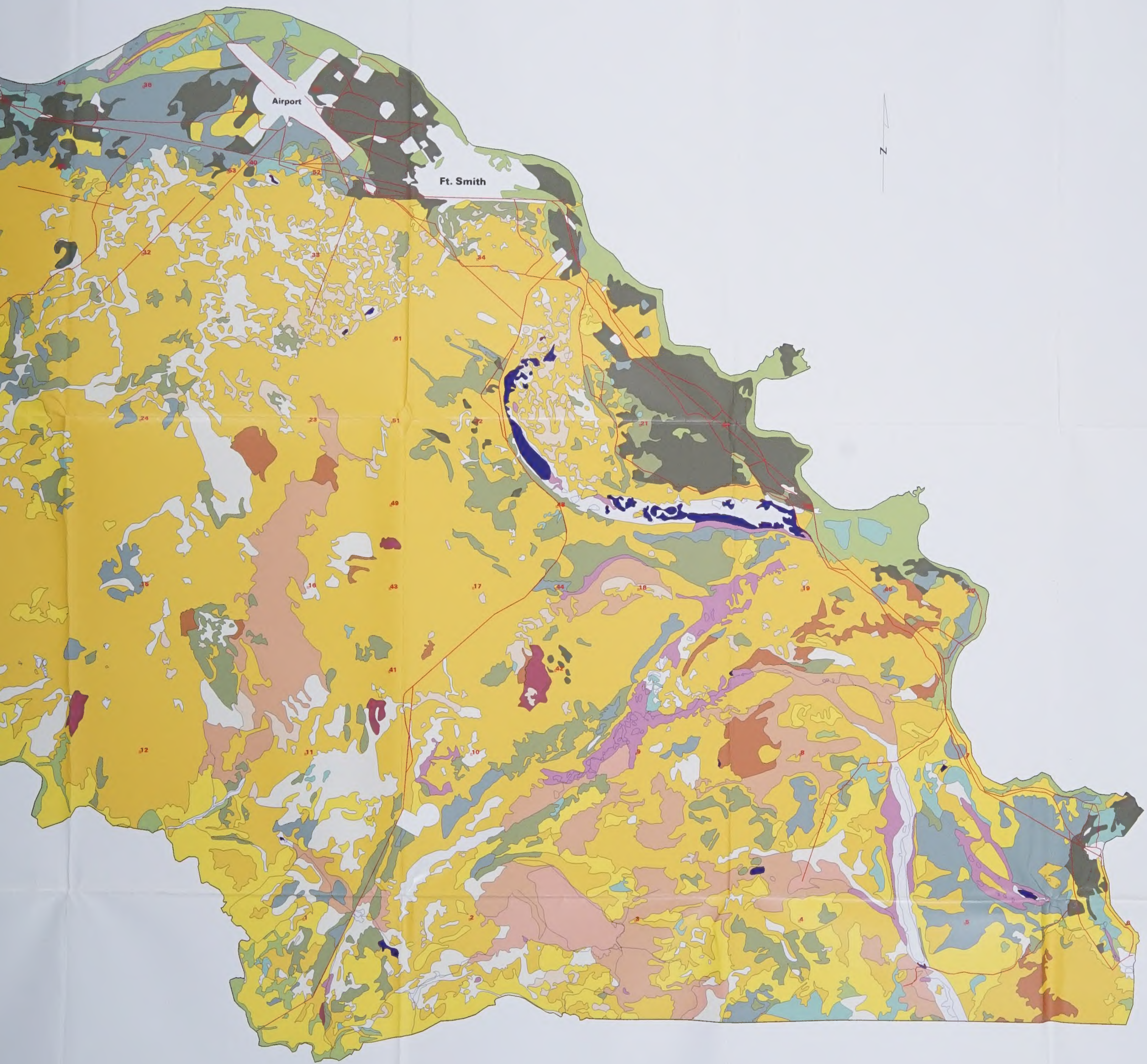
Recommendations

1) Since it is not feasible or desirable to eliminate all fires from the boreal forest, forest and fuel management must be considered. The minimum effort for protection of the community would be to modify the fuels in the northern and eastern corridors to reduce the spread of fire. Additional efforts could be expended in modifying natural fuel breaks in order to establish permanent lines of defence. Prescribed burning could be used to reduce the fuel build-up and improve fuel breaks.

2) Computer modelling of fire management scenarios could be developed to relate to the severity of drought conditions and the heterogeneity of the landscape. This is particularly important in terms of establishing lines of defence within the complex arrangement of fuel breaks and predicting fire behaviour.

Vegetation Classification o
Using the Alberta W

n Classification of the Fort Smith, NWT Area
sing the Alberta Wetlands Inventory



Scale 1:50,000

0 1 2 3 4 Km

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